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DEVELOPMENT AND QUALIFICATION OF ROCKET CATAPULT MK 1 MOD 0 AND MK 2 MOD 0 (AIRCRAFT EJECTION SEAT) (RAPEC I AND RAPEC III)

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ABSTRACT. This report describes the development, final qualification, and production of the Rocket Catapult Mk 1 Mod 0 and Mk 2 Mod 0 (Aircraft Ejection Seat), formerly known as RAPEC I and RAPEC III, respectively. A brief summary is given of the results of the final qualification tests conducted at various facilities.

The Mk 1 Mod 0 and Mk 2 Mod 0 rocket catapults permit a pilot to eject safely during the hazardous ejection conditions at take-off, landing, and high speed at low altitude.

DEPARTMENT OF THE NAVY · NAVAL ORDNANCE TEST STATION

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AN ACTIVITY OF THE BUREAU OF NAVAL WEAPONS

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FOREWORD

In 1957 it became evident from pilot ejection data that a system was needed for low-level as well as high-altitude ejections from high-performance aircraft. In August 1957 and again in April 1958, the U. S. Naval Ordnance Test Station (NOTS), in conjunction with various aircraft companies, was contracted to develop a low-level pilot ejection system. NOTS was specifically given the assignment of developing a rocket motor capable of ejecting the pilot successfully during take-off and landing conditions, as well as at high altitudes and relatively high speeds. The motor was to be capable of operating between -65 and 165°F and compatible with various Navy aircraft.

This report presents a review of the work done to develop the Rocket Catapult Mk 1 Mod 0 and Mk 2 Mod 0 (Aircraft Ejection Seat). The work was carried out under Task Assignment No. 242466-36089-91054 for the Mk 1 Mod 0 and Task Assignment 041-726/63089/01-060 for the Mk 2 Mod 0.

This report was reviewed for technical content by Frederick J. Miller and R. C. V. Reed.

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INTRODUCTION

Modern military aircraft, with their high performance and high speeds, require the most efficient systems possible that will permit a pilot to escape safely from a disabled aircraft. Before the advent of jet powered aircraft, pilot escape was a relatively uncomplicated procedure. In fact, from 1913 to 1940, 88% of all attempted bailouts from disabled aircraft were successful.

By 1955, however, only 40% of all attempted bailouts were successful because the pilots struck parts of the aircraft before they could clear its structure, or because wind blast or adverse forces prevented their escape from the cockpit.

Fighter pilots of World War II reported that when the German FW-109 aircraft was damaged the pilot seemed to jump about 40 feet from his aircraft. From these observations it was concluded that the German Air Force had developed a practical ejection seat for high-speed aircraft. This conclusion, and incidents in which pilots had been se· ›usly injured when exposed to the high-velocity slipstream, led to an investigation of the problems of emergency escape from high-speed aircraft. The concept of the ejection seat as utilized by the German Air Force was brought to this country and tested in 1946.

Aircraft ejections have increased sharply in number and complexity since 1944 because military aircraft speeds have increased from approximately Mach 0.5 to speeds exceeding Mach 2.0. Although not all of the problems have been solved, a great effort has been made by all activities interested in pilot safety.

A report on ejection and bailouts made by the U. S. Naval Aviation Safety Center, Norfolk, Virginia, in 1957 indicated that the rate of ejections had steadily increased since 1951. The ejection fatality rate had also increased. Figure 1 gives data on ejections compared to flying hours from 1951 through 1957. Data from the above mentioned report makes it evident that sufficient altitude is of paramount importance for a safe ejection. During 1957, 13 pilots were ejected below 1,000 feet and the results were fatal in all of the incidents. These somber data pointed to the inevitable conclusion that as of 1 January 1958 ejections initiated below 1,000 feet were almost certain to be fatal regardless of speed, automatic equipment, or attitude. These same data indicated that most low-altitude ejections were made under conditions that precluded optimal functioning of the ejection equipment.

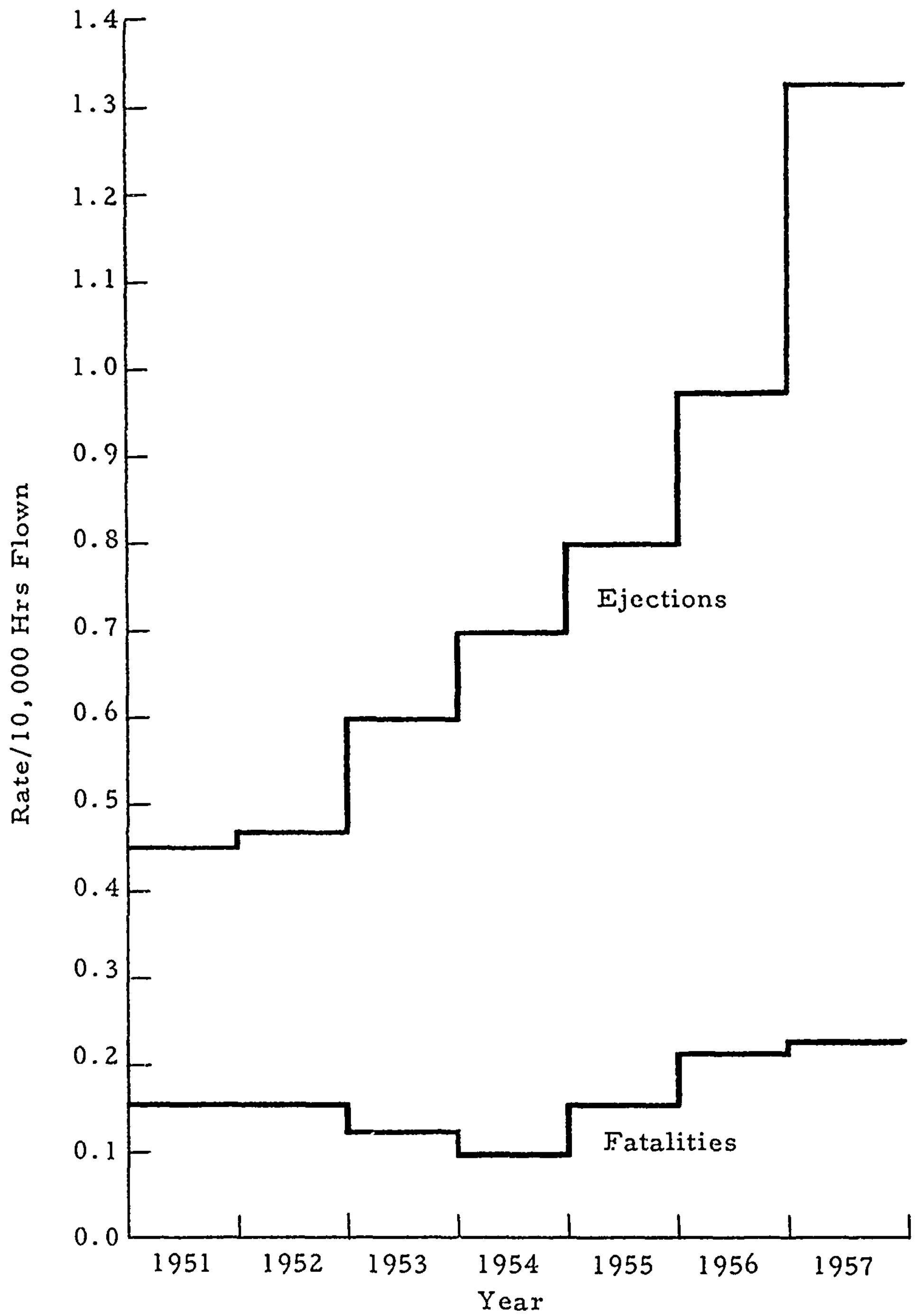

FIG. 1. Ejection Fatality Rate.

In the first half of 1958 three ejections took place at zero altitude. Two of the pilots escaped with serious injuries while the third sustained minor injuries. In none of the three ejections did the parachute deploy. The pilots remained in the seat up to the time of impact.

Clearance is only one problem of survival from a doomed aircraft. The pilot has to be protected from the high-velocity slipstream, which can cause serious injury. Assuming a successful ejection, windblast, flailing, deceleration, shock of the parachute opening, breathing and frostbite at altitude, and a safe landing are all factors relating to a successful escape. A successful escape is defined as one wherein the pilot returns to earth in a physical and mental condition sufficient to cope with the environment in which he is forced to land. He can then optimize conditions in order to facilitate rescue, or, if in enemy territory, he is capable of attempting to prevent being captured.

This report concerns only one phase of a successful escape—the ejection of a pilot by a rocket catapult system. Two such systems were developed at the Naval Ordnance Test Station (NOTS) to provide, primarily, an ejection seat with ground-level capabilities since 65 percent of all aircraft failures occur during take-off or landing.

The first unit was designated Rocket Catapult Mk 1 Mod 0 Aircraft Ejection Seat (RAPEC I) and replaced the NAMC Type II Catapult in the Navy A4D series aircraft. The development program was started in July 1957.

The second unit was designated Rocket Catapult Mk 2 Mod 0 Aircraft Ejection Seat (RAPEC III) and will replace the Martin-Baker gun catapult. The gun is part of the English-developed Martin-Baker seat system presently used in thirteen Navy aircraft. Development of the Mk 2 began in April 1958 and was augmented by information developed by the Mk 1 program.

Although the Mk 1 and Mk 2 are similar in configuration, this report will cover the two development programs in separate sections.

DESIGN RESEARCH

A research of information gathered by others engaged in ejection systems set forth the physiological limitations that a human body can withstand. These basic limitation factors were used as a guide for the design of the rocket catapult.

It was found, in general, that the maximum acceleration tolerated by a pilot in a seat is 24 g for 0.1 second or 17 ± 1 g for 0.4 second, and that the rate of acceleration change with respect to time (onset rate) is

250 g/sec maximum. In other words, it is not only important to limit the maximum g loading but also to limit the speed at which the g loading is applied. Since this early work, considerable studies have been initiated to more accurately determine physiological limits.

The major factors considered in the design of the ejection system were the acceleration and deceleration forces and the rate of tumbling applied to the pilot. Also the opening of his parachute while traveling at a high rate of speed had to be avoided. Aerodynamic forces on the pilot during high-speed ejections are a serious factor. Figure 2 presents a typical deceleration-injury curve.

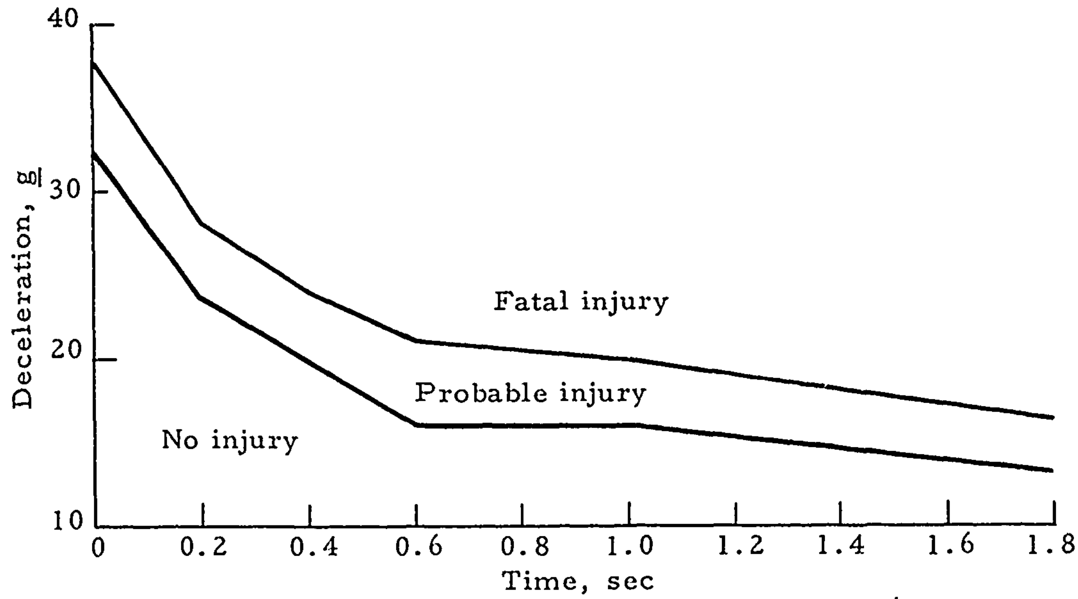

FIG. 2. Deceleration-Injury Curve.

The cartridge-type catapult has been in use for many years, but it does not have low-altitude capabilities. In order for the cartridge-type catapult to have these capabilities, it would be necessary to increase the size and energy of the cartridge. When a more powerful cartridge is used, the g load imposed on the pilot is in excess of physical limitations.

Another system that has been developed ejects the pilot downward through the bottom of the aircraft. This method allows the pilot to escape from the aircraft without hitting the tail surfaces, but it does not afford low-altitude capabilities. In this method of ejection, less force is required because the physical capabilities necessary to withstand a g load directed down the spine are much less than those necessary to withstand a g load directed up the spine.

In order for a pilot to eject safely from an aircraft the following conditions must be met:

1. He must be ejected free of the aircraft under conditions he can physically stand.

2. The ejected altitude must be sufficient to allow the deployment of his chute for safe descent.

3. His forward velocity must be slow enough to allow safe deployment of the chute.

4. His deceleration and tumbling after leaving the aircraft must be within physical tolerances.

The Mk 1 and Mk 2 Rocket Catapults were designed to satisfy these conditions during take-off, landing, high speed at low altitude, and at other less hazardous ejection conditions.

From investigation it was found that a high-thrust rocket with a short burning time was required to give the most desirable ejection characteristics.[1] Although these investigations were concerned with a unit larger than the Mk 1 and Mk 2, the requirements are similar.

ROCKET CATAPULT MK 1 MOD 0

The Rocket Catapult Mk 1 Mod 0 (Fig. 3) is a self-powered mechanically initiated, two-phase, solid-propellant booster and sustainer rocket. It has been designed to eject a 365-pound man–seat mass from an A4D aircraft at accelerations within the physical tolerances of the human body and to an altitude sufficient for parachute deployment.

Since the Mk 1 had to be capable of ejecting from take-off and landing conditions to Mach 0.95 and also be interchangeable with the NAMC Type II catapult, the necessity of obtaining maximum performance from a package of marginal size was a primary design requirement. A cutaway view of the unit is shown in Fig. 4.

Table 1 lists the design requirements to which the Mk 1 was successfully developed, qualified, and released for production.

[1] U. S. Naval Ordnance Test Station. Internal Ballistic Design and Trajectory Analysis of a Rocket Assisted Personnel Ejection Seat, by James L. Bray. China Lake, Calif., NOTS, 17 October 1947. (NAVORD Report 5433), UNCLASSIFIED.

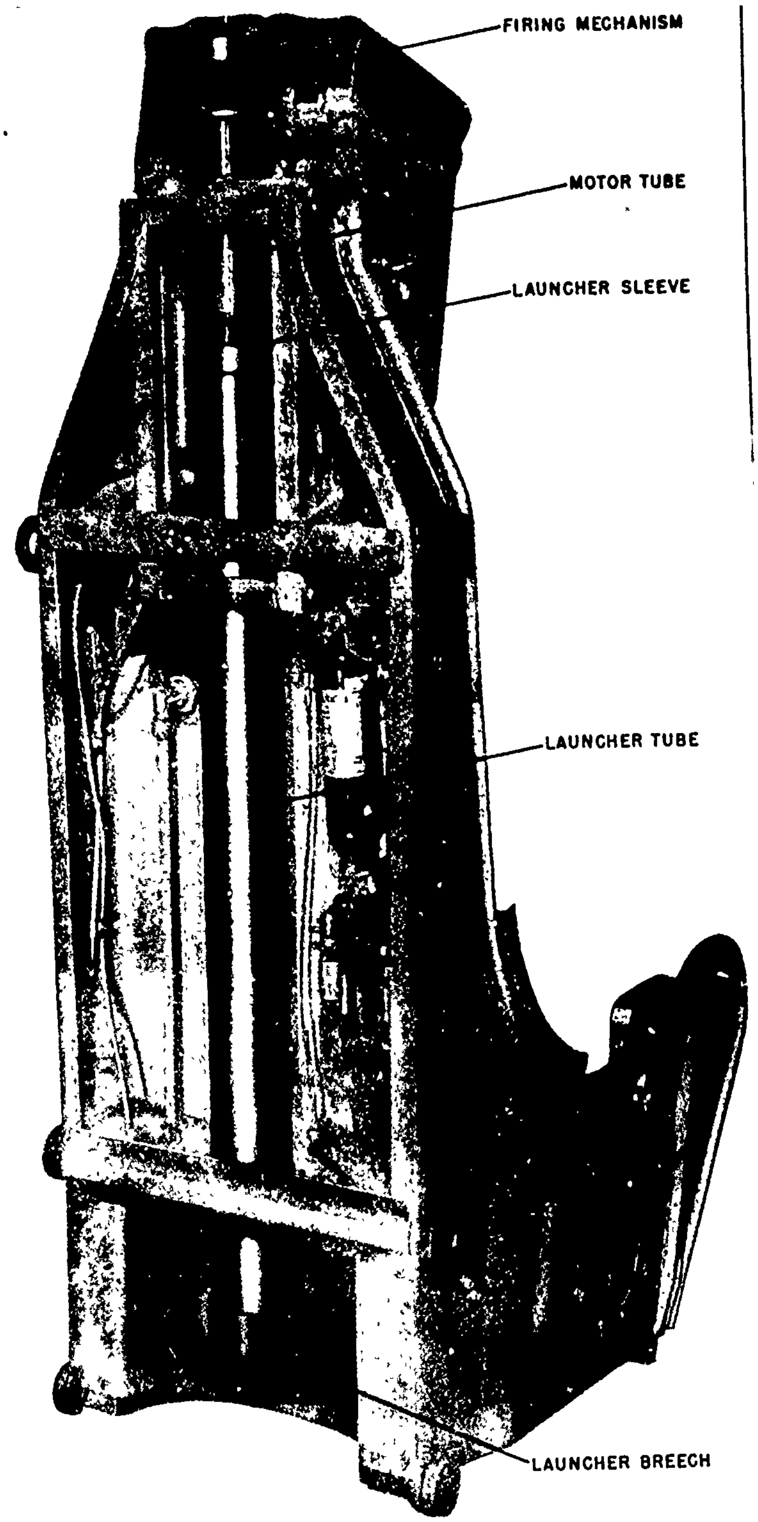

FIG. 3. Rocket Catapult Mk 1 Mod 0 Aircraft Ejection Seat Installation.

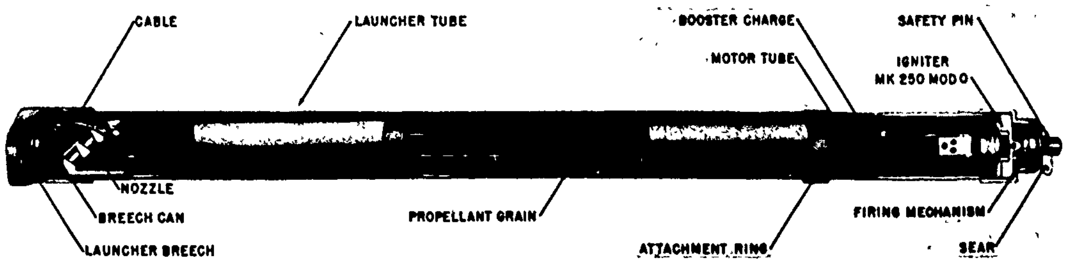

FIG. 4. Cutaway View of Rocket Catapult Mk 1 Mod 0.

TABLE 1. Design Requirements

Fit NAMC Type II envelope	Length-diameter
Acceleration (max.), g	18
Onset rate of acceleration (max. during any 30 ms), g/sec	250
Firing temperature limits, deg F	-65 to 165
Useful life (shelf and service), years	5
Ejection speed (max.)	Mach 0.95
Ejection Altitude (min.), ft	0
Maximum angular deviation of nozzle alignment, deg	1/2
Probability of gross malfunction	0.0001

The rocket catapult was documented and released to production in February 1960. Table 2 lists the assemblies and their Mk and Mod numbers. The applicable drawings are listed in Appendix A.

TABLE 2. Mk 1 Mod 0 Assemblies

Assembly	Mk and Mod No.
Loaded	Mk 1 Mod 0
Propellant grain	Mk 60 Mod 0
Primary igniter	Mk 250 Mod 0
Auxiliary igniter	Mk 189 Mod 0
Firing mechanism	Mk 28 Mod 0
Shipping container	Mk 217 Mod 0

The Mk 1 consists of a booster phase acting as a gas generator that develops pressure in the launcher breech to lift the man-seat mass out of the aircraft. The sustainer phase is mechanically initiated as the rocket motor clears the launcher tube and propels the man-seat mass to a sufficient height for man-seat separation and parachute deployment.

Table 3 gives physical and ballistic characteristics of the Rocket Catapult Mk 1 Mod 0.

Typical thrust-time, acceleration-time, and pressure-time curves are shown in Fig. 5–7. Definitions of static firing terms used in Fig. 7 are contained in Appendix B.

TABLE 3. Summary of Physical Characteristics and Ballistic Data

A. Principal Data	
Length (overall), in.	45.623
Diameter, in.	
Principal	2.719
Maximum	3.250
Weight, lb	
Loaded	27.15
Expended	20.00
Time of burning (t_b at 70°F), sec	0.50
Thrust (average over t_b along longitudinal axis), lbf	4200
Total impulse, lbf-sec	1400
Nozzle expansion cone angle, deg	28
Temperature limits, deg F	
Firing	-65 to 165
Storage	below 90
Acceleration limits, g	
Positive	5
Negative	3
Propellant weight to man-seat weight, avg ratio	0.05

TABLE 3. (Cont'd)

B. Dimensions of Inert Parts

	O. D., in.	I. D., in.	Length, in.	Material
Motor tube	2.63	2.56	39.75	Steel
Nozzle	-	-	3.0	Steel
At end of cone	2.56	-	-	
Throat diameter	-	0.46	-	
Igniter assembly	-	-	-	Aluminum
Booster phase	1.06	-	0.68	
Sustainer phase	0.15	-	0.56	
Launcher tube	2.81	2.74	33.50	Steel
Booster tube	1.00	0.87	36.78	Steel

C. Propellant Data

Propellant designation	
Booster phase	N5 and HE X 12
Sustainer	HE X 12
Propellant composition	Nitrocellulose, Nitroglycerin
Flame temperature (isobaric), deg K	2692
Method of manufacture	Extruded
Physical characteristics of grains:	
Booster	
Number	3
Configuration	flat strip
Length, in.	32.0
Diameter, in.	-
Web, in.	0.080
Propellant weight, lb	-
Restrictor (inhibitor)	
Material	Ethylcellulose
Place of attachment	All surfaces
Method of application	Dipped cement
Thickness, in.	0.006
Sustainer	
Number	1
Configuration	6 pt. star
Length, in.	37.9
Diameter, in.	2.53
Web, in.	0.397
Propellant weight, lb	7.10

TABLE 3. (Cont'd)

Restrictor (inhibitor)	
Material	Ethylcellulose
Place of attachment	O.D. and one end
Method of application	O.D. tape wrapped
Thickness, in.	0.070 - 0.090
Design parameters	
Port-to-throat area ratio, l/J	Sustainer 1.86
Design progressivity	Neutral
Exhaust-gas composition, mole %	
Mole hydrogen	11.07
Atomic hydrogen	0.09
Water	23.93
Carbon monoxide	38.47
Carbon dioxide	13.46
Nitrogen	12.52

D. Performance

	-65°F	70°F	165°F
Action time (t_a), sec			
Booster phase	0.240	0.190	0.170
Sustainer phase	0.450	0.375	0.360
Maximum pressure (P_m), psi			
Booster phase	1100	1100	1100
Sustainer phase	4500	4500	4500
Average pressure (P/t), psi			
Booster phase	-	600	-
Sustainer phase	-	2450	-
Total impulse (I) (aug), lbf-sec	-	1400	-
Propellant specific impulse (I_{sp}), lbf-sec/lbm	163	178	170

E. Ignition

Igniter description	
Primary	Percussion actuated
Auxiliary	Frame actuated
Igniter charge	
Primary	Boron potassium nitrate
Auxiliary	Zirconium lead dioxide
Ignition delay (t_d), ms	
Primary	12 at 70°F
Auxiliary	Not measurable

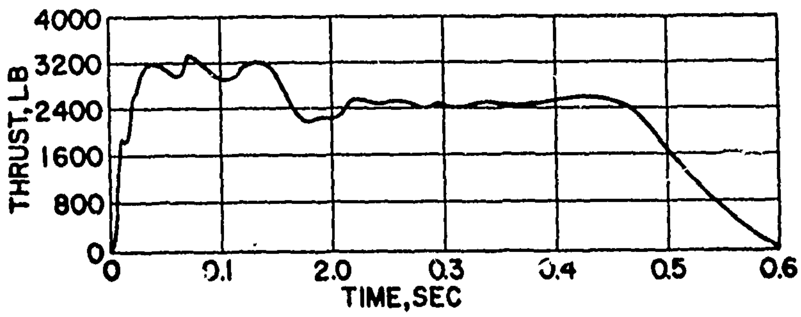

FIG. 5. Typical Thrust - Time Curve, Mk 1 Mod 0.

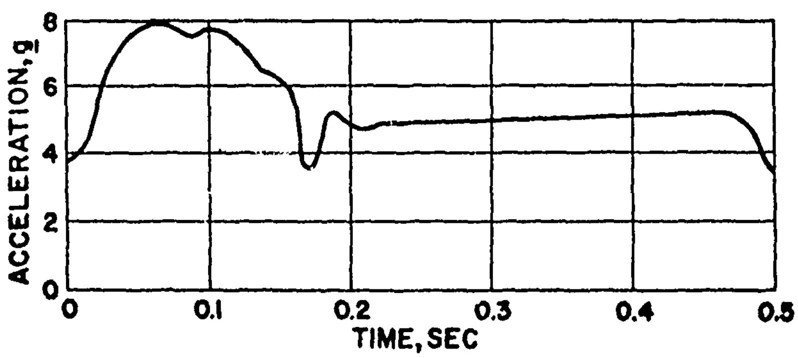

FIG. 6. Typical Acceleration - Time Curve.

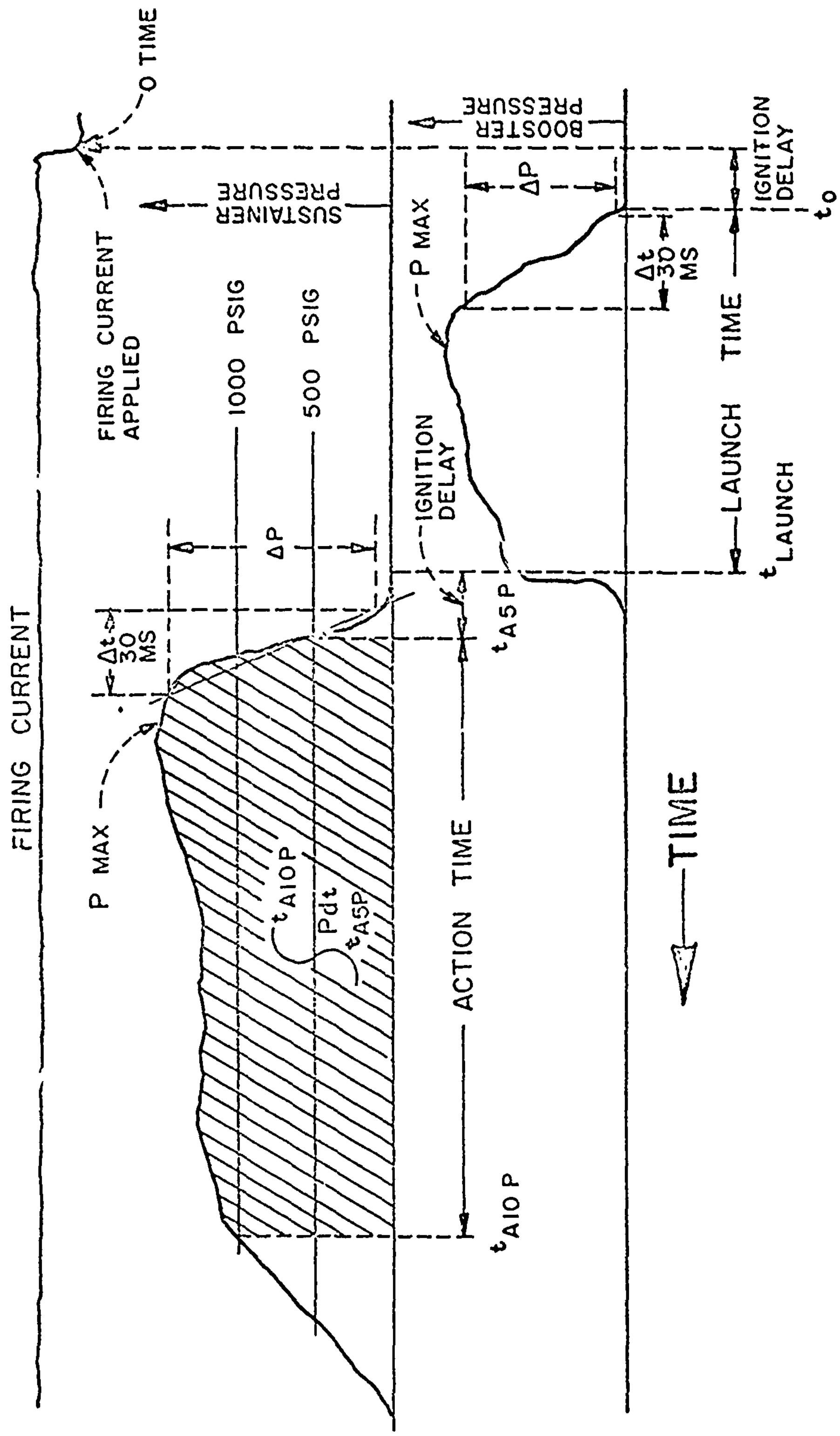

FIG. 7. Typical Pressure - Time Curve.

DEVELOPMENT

The development program was initiated by investigating two approaches to catapult design—the cartridge-rocket concept and the dual-thrust concept.

Cartridge-Rocket Design

The cartridge-rocket design incorporated two independent systems in the catapult, the cartridge-boost system occupying the lower end of the launcher tube, and the rocket sustainer system occupying the space in the upper portion of the launcher tube.

Because the cartridge unit required a large free volume for the expansion of cartridge gases, it was necessary that the initial volume of the chamber be approximately one-third the total volume of the launcher tube chamber. This was necessary to prevent excessive onset rates.

In normal catapults, cartridge gas is the only force used to eject the seat out of the aircraft, and because the cartridge is small the catapult tubes can be easily designed with a large initial free volume. However, by adding a rocket to the system, the volume previously unoccupied is now filled leaving no free space for the expanding cartridge gas.

It was found that cartridges could be designed to operate with as little as 15 in^3 initial free volume and with expansion ratios as high as 20:1. Fifteen cubic inches could not be spared and still have room for a sufficiently large rocket grain.

The cartridge in the breech of the launcher was actuated by a cable from the top of the unit. It was necessary to run the actuating and control cables down the inside rather than the outside of the motor tube because if space outside were used for this purpose, the allowable size of the catapult would be smaller, accordingly.

The firing mechanism for the sustainer grain was located at the top of the motor and was actuated by a cable attached to the breech so it would function at the correct time. This placement of the firing mechanism also gave initial ignition at the top of the grain instead of unwanted nozzle ignition.

At this point in the development of the cartridge-rocket system, the dual-thrust system was showing promise of being successful, and tests showed that its final impulse was greater than the cartridge-rocket motor. Therefore, because the cartridge-rocket design was more complex and less powerful, it was discontinued in favor of the dual-thrust system.

Dual-Thrust Design

The dual-thrust system incorporates the sustainer and booster phases in the same motor tube. This is possible because the booster phase occupies part of the internal perforation of the rocket grain. Therefore, because no space is occupied by the conventional cartridge, the rocket motor is longer and more propellant is available to increase the total impulse. The first phase ignites the second phase, thereby eliminating the need for a second ignition system.

FIRING MECHANISM. As a requirement, the firing mechanism had to be a mechanical device, as opposed to a chemical or electrical one. A spring-loaded mechanism was chosen with a trigger requiring about the same motion and pull as that of the NAMC Type II Catapult. A flat helical spring was used to conserve space.

Because it was desirable that the firing mechanism be dust and moisture resistant, a unit with a minimum number of openings and exposed parts was necessary. A further requirement was that the firing mechanism could be actuated from any position around its 360-degree periphery. This was necessary because the firing mechanism was a screw-on type.

During the early development of the rocket catapult, the igniter required a forceful primer producing about 120 in-lb to actuate it. The flat helical spring in the firing mechanism was capable of delivering this force. Later the more sensitive Mk 106 Mod 0 Primer was used, although the heavy firing pin spring was retained. The firing pin protrudes 0.045 to 0.055 inch when in the fired position. Excessive penetration of the primer is critical and blow back may result if the primer top is penetrated by the firing pin.

The firing mechanism has been designated Mk 28 Mod 0 (Fig. 8).

PRIMARY IGNITER. The primary igniter was originally designed as an integral part of the head closure, but because it was difficult to make and awkward to handle, a self-contained unit was designed and developed. This unit (Fig. 9) was designated Igniter Mk 250 Mod 0.

The first designs and early tests of the primary igniter were based on existing ignition systems. It was believed that a flash tube containing a pyrotechnic mixture was necessary, which would be ignited by the arming primer. A crimped diaphragm would then rupture, blowing the burning igniter mixture onto the propellant strips. Two factors were ascertained during early tests: (1) that a flash tube was not necessary; and (2) of the pyrotechnic mixtures tested (FFFG Black powder, cannon black powder-perfluorobutyl acrylate mixture, and boron-potassium mixture) only the boron-potassium nitrate mixture was suitable.

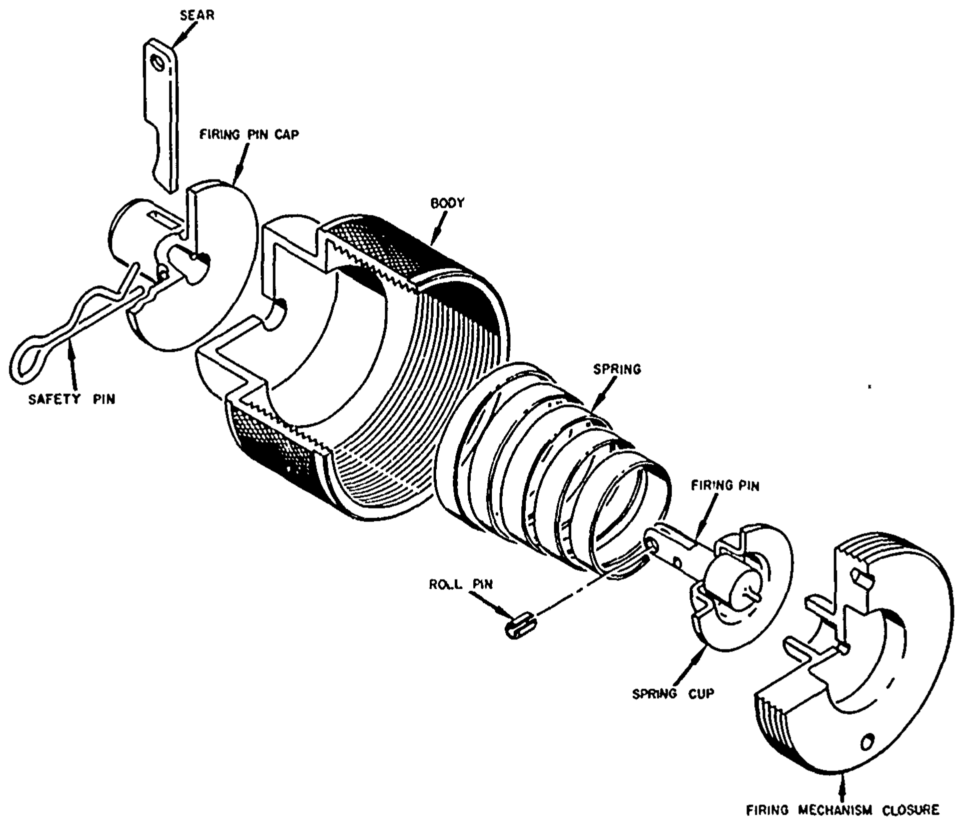

FIG. 8. Firing Mechanism Mk 28 Mod 0.

The igniter was fabricated in two pieces so that the primer could be installed separately in the cap. The igniter case was stamped so that the thinned area in the bottom would serve as a blow-cut diaphragm. The parts were assembled by cementing the mating surfaces together with a cold-setting epoxy cement. These parts had been fabricated from aluminum, steel, bronze, and copper. Aluminum proved to be adequate and was used in the final design. The primer was pressed into the cap. 4 1/2 grams of boron-potassium nitrate pellets were installed in the case, and the case was then bonded to the cap. The Bureau of Weapons requested that Primer Mk 106 Mod 0 be used because of logistics.

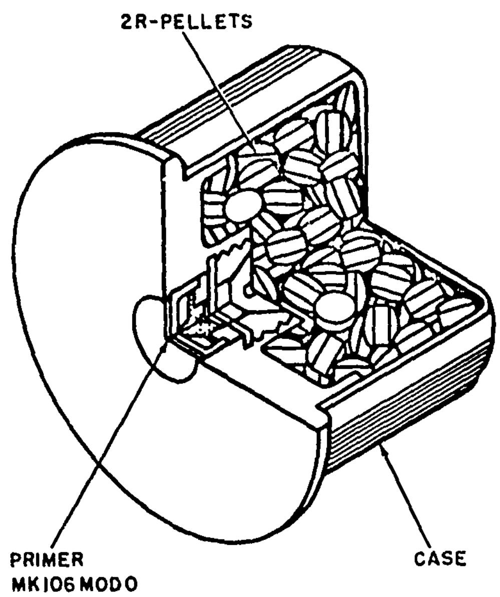

FIG. 9. Igniter Mk 250 Mod 0.

In order to gain more surface area for the pellets, to provide fewer edges for abrasion, and to provide uniform compounding, a program was initiated to modify the cylindrical pellets into spherical pellets. It was found, however, that spherical pellets were difficult to manufacture because the pelletizing machines sheared the pellets on extraction. Therefore, the final pellet shape was determined to be 0.125 inch in diameter and 0.090 inch thick and designated as 2R pellets (NOTS Model D-672B).

Tests were performed to determine

1. Reaction and relative gaseous energy release by the closed-bomb technique.

2. Leakage around the primer.

3. Effect of humidity on the epoxy seal.

4. Performance when varying the composition of the boron and potassium in the 2R pellets.

5. Effect of varying the density of the 2R pellets.

6. Effect of altitude to 120,000 feet.

7. Effect of temperature from -65 to 165°F.

The igniter performed reliably in a time-span of 2 to 3 ms from initiation of the Mk 106 Mod 0 primer to release of hot igniter gas.

During the final qualification program several units misfired. The malfunction was traced to the dimensional relationship between the igniter primer and the firing pin. Reliable performance was achieved by establishing the depth of the primer to a minimum of 0.002 inch and a maximum of 0.008 inch below the surface of the igniter cap.

Loading instructions require 100 percent functional inspection of the firing mechanism and the primer depth.

BOOSTER ASSEMBLY. The design of the booster assembly was changed several times before a final design was selected (Fig. 10). The original tube design was 1 1/8 inch in diameter with seventy 1/8-inch holes drilled in it. The propellant was held to the side of the tube with silicone tape. When the booster propellant burned through, the holes opened and hot gases flowed from the booster tube to the motor tube and ignited the sustainer grain. The thickness of the booster propellant and the rate of burning determined at what time after booster ignition the sustainer grain would ignite. When the sustainer grain ignited, the booster tube remained intact. Under these conditions there was no excessive pressure, plugging of the nozzles, or uneven burning of the sustainer grain. This was a time-dependent ignition system rather than a position-dependent system, and for correct operation a position-dependent system was necessary.

Several motors of this design were tested and the system performed successfully. However, it was found that the booster burnthrough time varied, and therefore the time lapse until sustainer grain ignition was not reproducible. At the velocity the rocket motor is separating from the launcher tube, 10-ms difference in time means several inches of travel. When ignition is premature, and the sustainer grain ignites while the motor tube is in the launcher tube, an extremely high acceleration results. When ignition is late, and the rocket ignites too far outside the launcher tube, a loss of efficiency and a drop to zero g results, followed by a sudden rise in acceleration when the grain ignites. Variable factors affecting the rate at which the seat accelerates, that made it difficult to achieve constant results, were

1. Temperature

2. Friction from seat guide rails

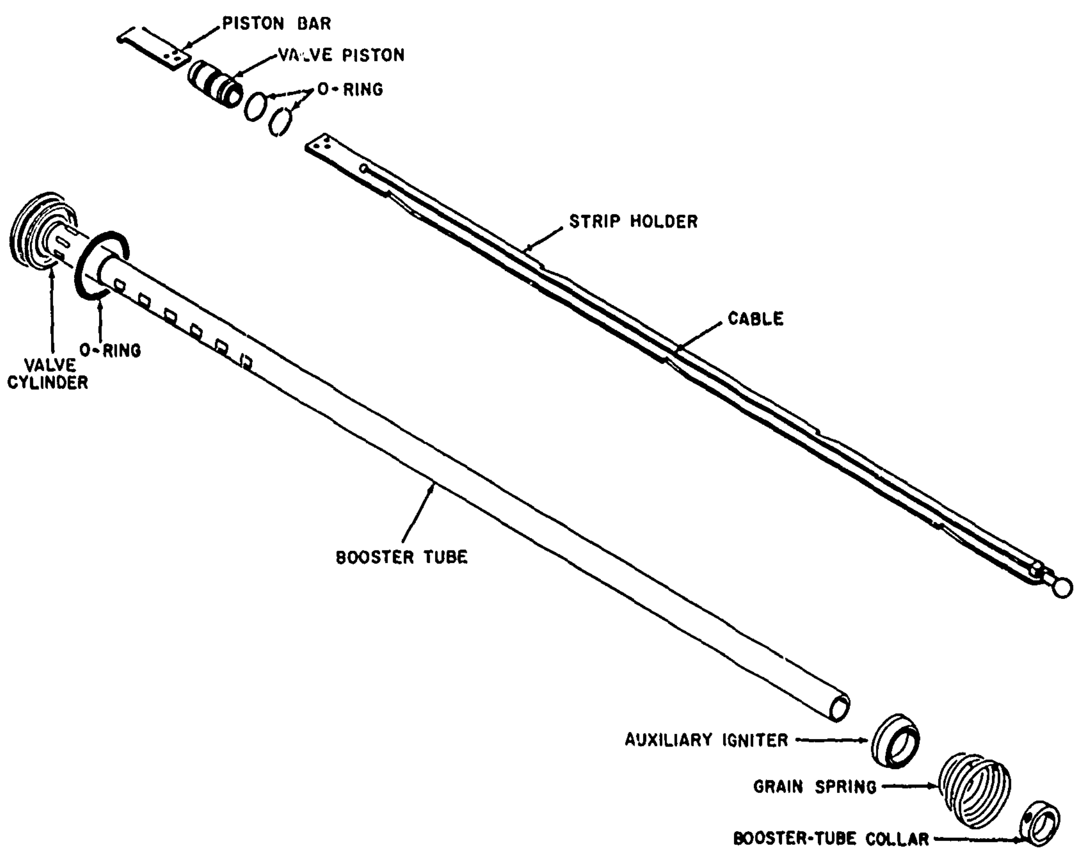

FIG. 10. Booster-Tube Assembly.

3. Burning rate of booster propellant

4. Man-seat weight

The burnthrough design was modified to include a holder for flat sheets of booster propellant (one strip of N-5 and two strips of High Energy X-12). A few holes at the forward end of the booster tube were covered with this propellant, thus simplifying manufacture of the booster section and eliminating grain ignition down in the perforation. During firing, the strip holder tended to jam against the side of the booster tube because of pressure differential. This was solved by cutting V-shaped notches in the strip holder.

It was found that top ignition of a grain is preferable because at cold temperatures gases can pressurize the annular space between the motor tube and the grain, thus preventing grain fracture. During

grain burning, a difference in pressure exists between the outside and the perforation of the grain that is sufficient to crack the grain unless the annulus is quickly pressurized. This condition is common if the grain is ignited down in the perforation.

Several tests were made with a position-dependent ignition system in which the sudden pressure drop of the motor leaving the launcher caused a plug or piston to be pulled in the nozzle, diverting gas from the booster tube into the lower end of the motor chamber. Some of these tests were successful. However, this system would only ignite the grain after the motor left the launcher, thereby causing a drop to zero acceleration and then a sudden rise in acceleration when ignition took place. This system was also subject to the disadvantage of nozzle end ignition, which is not desirable because of the pressurization of the annulus mentioned previously. Forward support of the grain would be required to allow gases to flow into the annulus at the after end of the grain. This is a difficult and complicated design and was discontinued in favor of a more suitable one.

Later designs used a cable, coiled in the breech, to pull the piston rather than depending on pressure differential to do it. This system was more positive and allowed ignition of the grain when the motor was still in the launcher tube, thus eliminating the rapid loss and then gain of acceleration outside the launcher tube. The system retained the fault of nozzle end ignition, and this complicated the nozzle design for reasons previously mentioned.

The slider valve concept, which was adopted and incorporated in the cable design, seals six gas ports in the top of the booster tube until sustainer grain ignition. As the motor tube rises to approximately 36 inches from pressure caused by booster burning, the cable becomes taut and exerts a pull on the slider valve, thereby opening it and igniting the sustainer grain.

A problem was encountered when the valve-piston bounced back to its original position, thereby closing the gas ports before ignition could occur. This problem was solved by making a chamfered seat into which the valve forces itself when actuated, thus expending the energy required to bounce back.

A gas leak around the valve-piston, causing preignition of the sustainer grain, was noted during final qualifications. Increasing the diameter of the piston to 0.934 inch eliminated grain preignition.

In early tests with the slider valve, a light-weight cable looped in the booster tube or coiled in the breech was used to pull the slider valve piston. This system failed because the cable snagged on the nozzle plate causing preignition of the sustainer grain.

A shorter cable that would not have to be coiled was then tested but it was not heavy enough to resist heat and erosion. At present, a heavier cable is used that has fewer strands and, therefore, more resistance to heating and corroding effects. The cable slides through the booster nozzle throat so that one spot is not continuously exposed. Neither the 7 by 19 cable nor the 7 by 7 cable of 3/32-inch stainless steel was as successful as the 1 by 7 cable (with a test acceptance pull of 2,500 lbs) now used. The cables are designed with a ball swaged on each end; one is held in the breech cup by a retainer nut and one shears off after the slider valve is actuated. The cable is out and away from the motor when the end shears off, thereby eliminating the possibility of its blocking any of the nozzles.

Some difficulty was encountered when the cable passed through the nozzle if sharp edges were present. The cables would bind or break at this point rather than pull the slider valve piston. This condition was corrected by machining a 0.187 x 0.220-inch slot in the nozzle for the cable to pass through. This machined slot in the nozzle allows the cable to be straight in its position in the booster tube with as little bend as possible where it passes through the nozzle.

The head closure (the valve cylinder and forward end seal) was not originally part of the booster tube. However, it was found that a more reliable operation could be obtained if they were one piece.

The booster tube is large at the forward end for a number of reasons: (1) to allow the valve piston to be as large as possible to reduce restriction in this area, (2) to allow gases from the primary igniter to pass easily through to the booster tube, (3) to allow hot gases from the booster to get into the sustainer chamber without constricting it, and (4) to allow gas from the sustainer grain to flow back through the booster tube. The remainder of the tube is smaller to allow a maximum amount of port area between the outside of the booster tube and the inside of the grain perforation.

Flats are machined in the booster tube wall that break through about 0.025 second after sustainer ignition. The break-through flats prevent erosion of the booster ports. If much gas from the burning sustainer grain were forced back through the six gas ports in the valve cylinder, severe erosion would occur. The break-through flats, by allowing most of the gas to pass through them, keep the webs between the gas ports intact. The flats cannot be machined too deeply, or they will rupture during booster firing and cause preignition. They are machined to a depth of 0.015 inch that allows break-through to occur from the outside of the booster tube and gas to enter the tube from the burning sustainer grain.

The elbow joint at the end of the motor tube allows the booster tube to expand longitudinally. If the fit is too tight, the booster tube may expand enough to damage the webs between the gas ports in the valve

cylinder. Damage to the valve cylinder can result in preignition. The lower 1-inch section of the booster tube and the inside of the nozzle are hard chromed to a 32-microinch surface finish, to maintain a 0.005-inch clearance that will prevent gas leakage at the elbow joint and yet allow for expansion.

AUXILIARY IGNITER. Ignition of the sustainer grain upon valve piston opening became a problem, evident first in determining the proper cable length. Ignition of the sustainer was reproducible at ambient temperatures only if the valve piston was opened while the motor was still in the launcher tube. If the motor was permitted to leave the tube before valve piston action, ignition was not complete enough for the sustainer grain to support combustion. Since high acceleration forces would be transmitted to the pilot by firing the motor while it was in the launcher tube, additional methods to ignite the sustainer grain became necessary.

A nozzle base plate was designed to sustain pressure in the booster tube, which, in turn, would aid ignition. Also, an auxiliary igniter using 27% zirconium and 73% lead dioxide ($ZrPbO_2$) was designed to be ignited by the hot gases passing through the ports of the slider valve after piston action, which would ignite the sustainer grain.

As the firing temperature range was increased to -65 and 165°F the problem of sustainer grain ignition became more acute. Design solutions and results are listed below:

1. Increased the weight of $ZrPbO_2$ from 2 to 4 grams.

2. Added aluminum magnesium perchlorate and aluminum potassium perchlorate to the $ZrPbO_2$ mixture, which resulted in an increased burning temperature. Sustainer grain ignition failure was reduced but the grain cracked upon ignition. The igniter forced hot particles too far down into the grain perforations causing a pressure differential across the grain web and resultant cracking.

3. A cylindrical screen igniter was coated with $ZrPbO_2$ and placed in the counterbored head end of the grain. A 1/16-inch ethylcellulose disk was placed in the bottom of the counterbore to prevent grain penetration by the hot particles. Grain ignition delay was still excessive although improvement was noted.

4. Increased the weight of $ZrPbO_2$ from 4 to 6 grams.

5. The sustainer grain was post-cured for 72 hours at 140°F and painted with 1 gram of an auxiliary igniter mixture ($AlKClO_4$) on the counterbored head end. Without using the basic igniter, excessive ignition delays were experienced at -35°F.

6. A combination of a 4-gram $ZrPbO_2$ igniter, the counterbored post-cured grain, and a 0.010-inch-thick brass disk in the counterbore resulted in a solution that functioned over the temperature range without excessive ignition delay. However, the igniter failed during vibration.

7. The igniter can was redesigned to withstand vibration.

8. The igniter charge weight was established at 4.4 ± 0.2 grams of $ZrPbO_2$ with 2 percent poly-2-methyl-5-vinyltetrazole (PMVT) binder. PMVT is an easily ignited material that burns at low pressure with a hot flame.

The igniter mixture of $ZrPbO_2$ and PMVT is unaffected by moisture and does not have to be enclosed. Use of an open igniter was necessary because ignition delay or failure could occur if the igniter gases had to first break an enclosure.

A problem of batch-to-batch variations in density and sensitivity of $ZrPbO_2$ was solved to an acceptable degree by screening both the zirconium and lead oxide. It is believed that the particle size of the metal is the major factor controlling sensitivity. An attempt to form igniters by pressure was unsuccessful because the desired surface finish could not be achieved, due to the viscid nature of the material.

The Auxiliary Igniter Mk 189 Mod 0 (shown in Fig. 10) is shaped like a doughnut of rectangular rather than circular cross section. The mixture is placed in a groove in the rear of the auxiliary igniter.

SUSTAINER GRAIN. The sustainer propellant grain, designated as Mk 60 Mod 0, is a 6-point stator configuration (Fig. 11) made of

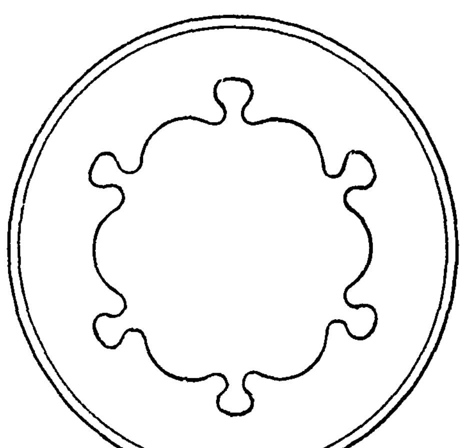

FIG. 11. Propellant Grain, 6-Point Stator Configuration.

High Energy X-12 double-base propellant. It is a nominal 2.5 inches in diameter, 38.0 inches long, 6.5 pounds in weight, and imparts a thrust of 4,200 pounds.

Five design changes were made to the original configuration. They are:

1. A raised inhibitor or grain collar on the forward end serves three purposes: (1) keeps the grain centered by use of the grain spring, (2) aids ignition of the sustainer grain, and (3) aids in preventing grain cracking at -65°F.

2. A counterbore (1.610 ID x 3.0 inches) was machined in the forward end to serve three purposes: (1) a safety feature to permit the grain to slip over the friction-sensitive auxiliary igniter in the event of a head-end drop, (2) provide a trap for hot particles from the auxiliary igniter to ignite the sustainer grain at -65°F, and (3) to allow free passage of sustainer grain gases back into the booster tube upon sustainer grain ignition.

3. An increase in the number of wraps of 0.0075-inch ethylcellulose tape from two to three wraps to prevent inhibitor collapse late in burning at intermediate temperatures (100 to 135°F).

4. The internal perforation of the grain was dipped with a 5 percent solution of ethylcellulose in Elba solvent. This serves three purposes: (1) controls the pressure rise rate in the motor, (2) reduces early maximum pressure peaks at 165°F, and (3) prevents sustainer grain cracking at -65°F.

5. Port area of the grain was increased to reduce early maximum pressure and overcome the problem of port area reducing with age. Increasing the port area from 1.78 to 1.86 in^2 reduced the early maximum pressure by 800 psi and also the total impulse by approximately 2 percent. This reduction in the total impulse did not affect the altitude during actual performance tests.

MOTOR ASSEMBLY. The final design of the motor tube assembly is shown in Fig. 12. Three design changes were made late in prototype evaluation. They are as follows:

1. The slot in the threaded section of the motor tube and the attachment ring were moved 60 degrees counterclockwise when viewing the catapult from the top. This provides a greater safety factor to withstand the forces exerted on the attachment ring during booster operation.

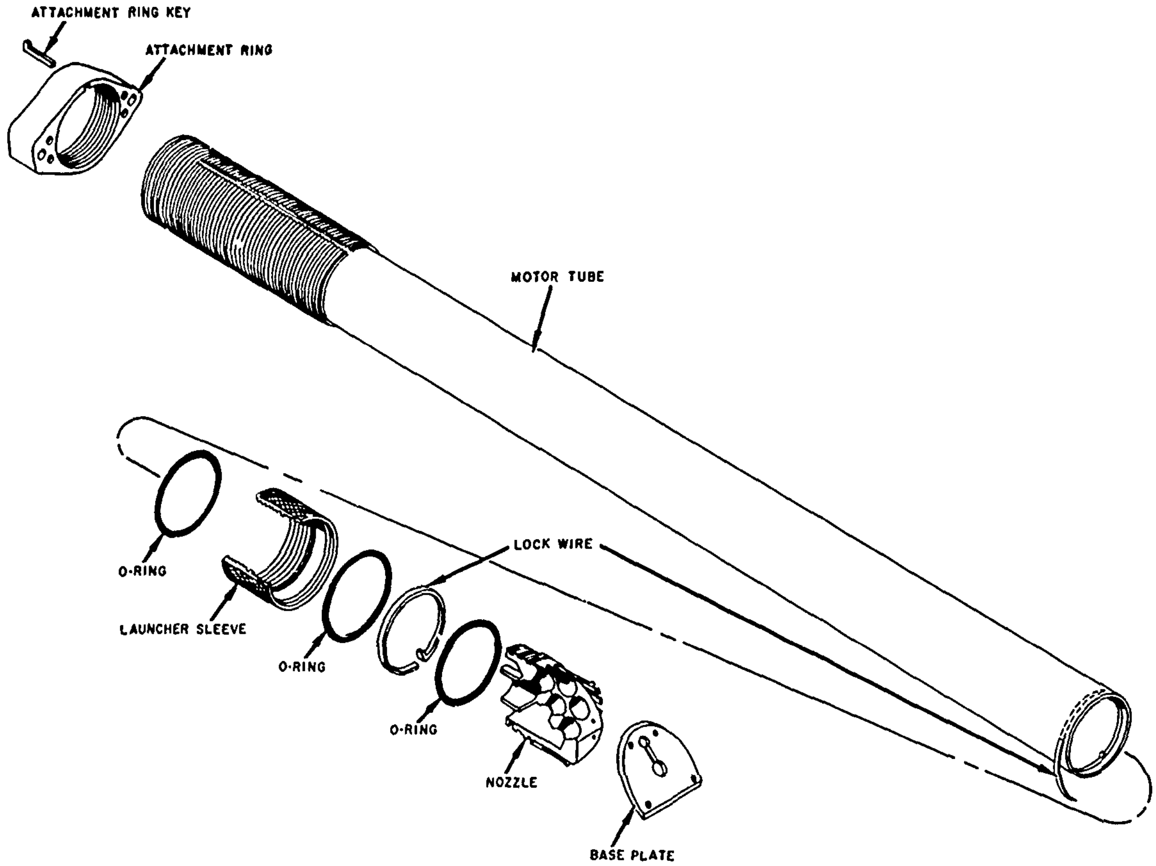

FIG. 12. Motor-Tube Assembly.

2. The launcher sleeve was added to form a dust and moisture seal between the launcher tube and motor tube, to give a shoulder for the launcher tube to rest on, and to serve as an adjustment to remove play out of the loaded assembly.

3. The orifice in the base plate was changed to prevent cable damage to the 0.005 to 0.006 inch thinned section during handling and shipping. The booster nozzle port has a surface finish of 63 micro-inches and is 0.005 to 0.008 inch thicker than the remainder of the plate. This change will allow all the force applied by the screw to be exerted in the booster nozzle area assuring a better seal for control of onset rates.

LAUNCHER TUBE AND BREECH ASSEMBLY. The final design of the launcher tube and breech assembly is shown in Fig. 13. The breech can, initially designed to be secured to the nozzle by two screws, is held in place by a spring. When pressure in the launcher breech reaches approximately 60 psi from booster operation, the spring is depressed allowing the breech can to disengage the nozzle-sleeve tangs from an internal ridge, which releases the motor.

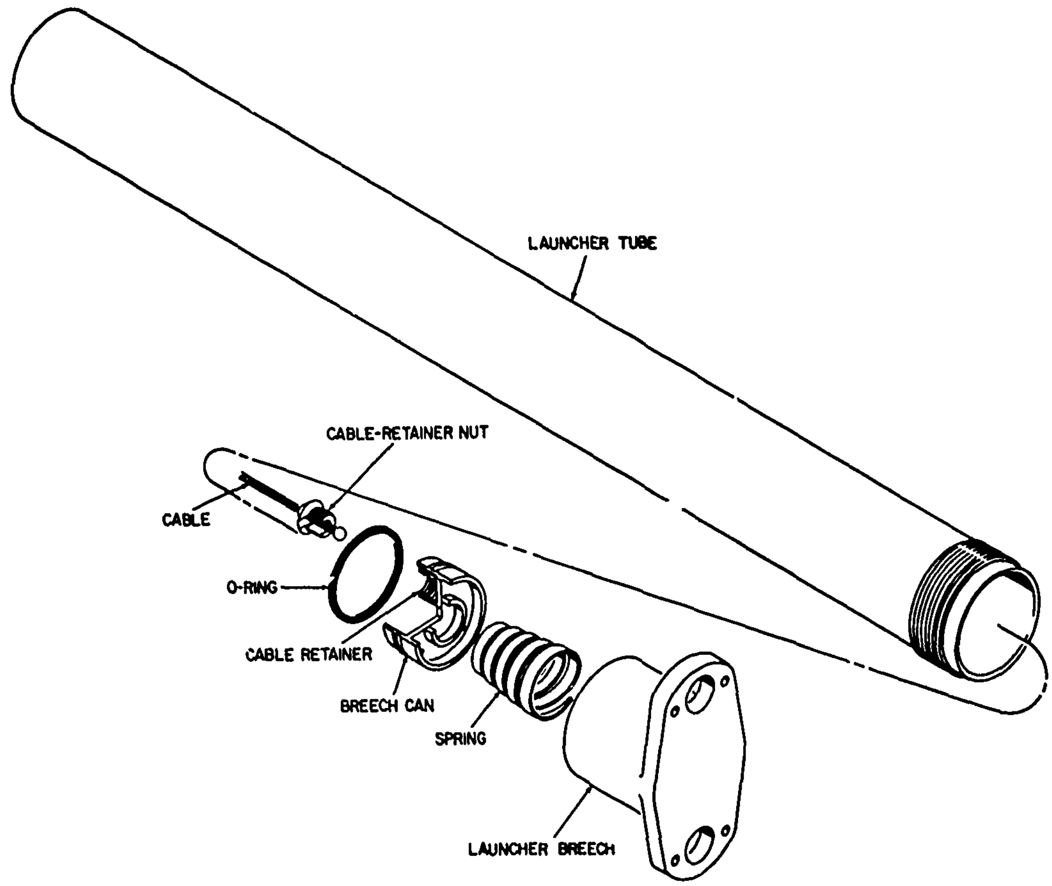

FIG. 13. Launcher Tube and Breech Assembly.

SHIPPING CONTAINER. Shipping Container Mk 20 Mod 0 (Fig. 14) is designed to transport two loaded Mk 1 Mod 0 catapults. The all-steel container has hard rubber supports at the forward and aft ends to provide isolation from vibration. The units are positioned in the container with the firing mechanisms reversed. Metal strips are used to secure the cover to the body of the container.

QUALIFICATION

Process Studies

ANNEALING AND POST CURING. Following standard procedures used in developing propellant grains, the extruded double-base propellant billets were annealed to relieve internal stress, thereby stabilizing their

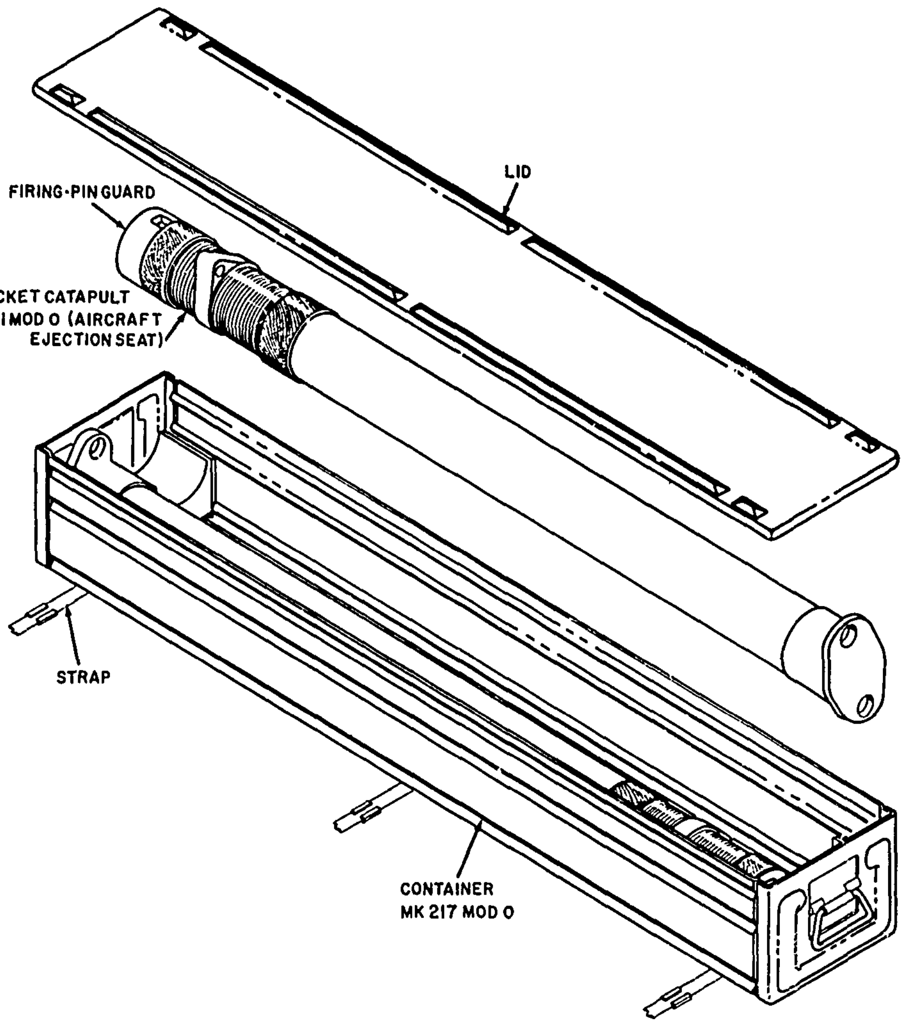

FIG. 14. Shipping Container Mk 217 Mod 0.

physical dimensions. Although fixed values of the dimensions are never attained they are approached over a period of time. During annealing and post curing, measurements of length, port volume, major and minor ID, OD, and wall thickness were recorded at all stages of manufacture and for every other day of a 30-day period, after the grains had been made.

Annealing billets at 130°F for 12 hours tends to relieve internal stress. Post curing of the propellant grain final assembly at 130°F for 96 hours had the most significant over-all effect on billet dimensions. Before this study, post curing was done at 140°F for 72 hours.

GRAIN INHIBITING. A study was conducted to determine if extrusion inhibiting or spiral wrapping was more suitable for producing grains that were dimensionally stable. Grains were produced using both methods and subjected to the following tests:

1. Temperature cycled five times from -65 to 165°F.

2. Accelerated aging as follows: (1) 90 days at 95°F; (2) 75 days at 70°F and 15 days at 95°F; (3) 10 days at 130°F and 30 days at 95°F.

Significant results of the tests are as follows:

1. The lengths of spiral-wrapped grains were more stable (had less shrinkage) than extrusion-inhibited grains.

2. The outside diameters of the spiral-wrapped grains increased; the outside diameters of the extrusion-inhibited grains decreased.

3. The inside diameters of the spiral-wrapped grains were more stable than extrusion-inhibited grains.

4. The wall thicknesses of the spiral-wrapped grains were more stable than extrusion-inhibited grains.

As a result of this study, the sustainer grain is spiral wrapped with three wraps of 1/2-lap 0.0075-inch ethylcellulose tape.

Functional Tests

AGING AND TEMPERATURE CYCLING. Four sustainer grains were loaded in static firing motor tubes, aged at 130°F for 10 days, and then temperature cycled five times from -65 to 165°F. The grains were X-rayed and no fractures were visible. Two of the grains were fired at 70°F and both functioned normally. The remaining two were not fired.

SURVEILLANCE. Ten loaded booster units, stored in a vertical position, were subjected to accelerated aging at 130°F for 10 days. Examination of the units throughout the 10-day period showed no visible changes. They were then temperature cycled five times from -65 to 165°F, which resulted in no visible changes.

Strips that were cut from the N-5 and the high-energy X-12 propellants during the storage period were given the strand-burning rate test. The test showed the burning rate of the X-12 propellant to be slightly lower after aging; inasmuch as this was not a significant change, the booster units were considered to be functional at the end of the surveillance period.

HYDROSTATIC TEST. The motor tube was hydrostatically tested to destruction. An initial pressure of 1,000 psi was applied and increased by 500-psi increments until the tube failed at the lockwire groove at 5,500 psi. Failure occurred approximately 360 degrees around the tube.

The heat treating process of the motor tube was changed to produce a tube with 125,000 psi yield strength. Six motor tubes, three of which had been fired, were then tested. An initial pressure of 1,000 psi was applied and increased by 500-psi increments until the tube failed at the lockwire groove at 6,800 to 7,000 psi. The average operating pressure is 3,000 psi.

FIRING MECHANISM PULL TEST. The force required to pull the sear on the firing mechanism is 10-20 pounds.

UNDERWATER TEST. A static test stand, rigged with a seat and dummy, was released just above the surface of the water. Ninety seconds after water entry, the motor was ignited. The chair, with the dummy intact, was recovered eight feet away from the test stand on the port side. Inspection of the rocket motor and launcher tube indicated that the launcher-separation phase had been normal.

Two additional tests ejected a seat and dummy out of an A4D cockpit in 15 feet of water. Both firings were successful.

Test results indicate that the system is capable of ejecting a man-seat mass from an aircraft cockpit at a depth of 35 feet or after 90 seconds submersion in sea water, whichever occurs first.

SIMULATED POSITIVE 6 g PULL-UP. The rocket catapult unit was fired against two 2.75-inch rockets which developed a combined thrust of 1700 pounds. The unit functioned normally, reaching a maximum of 10 g. The booster pressure was increased by approximately 250 psi and launch time was increased 15 ms.

SIMULATED NEGATIVE 3 g. The rocket catapult unit was fired against one 2.75-inch rocket which developed a thrust of 850 pounds. The unit functioned normally.

Safety

ROUGH HANDLING AND DROP TESTS. This series of tests indicated three design weaknesses and resultant safety hazards: (1) grain cracking after 2-foot horizontal drops at -65°F, (2) firing pin damage in head-end drops, and (3) occurrence of sustainer grain ignition three times during the tests. The following design changes were incorporated to make the unit safe when dropped:

1. A protective cap designed to fit over the firing mechanism eliminated damage in head-end drops.

2. A counterbore was machined in the forward end of the grain to encircle the auxiliary igniter.

3. A collar was placed on the front of the propellant grain inhibitor. The grain spring fits over this collar and centers the grain.

4. The auxiliary igniter can was tapered to reduce impact loading.

5. The igniter charge was placed flush with the surface of the igniter can. The previous design was extended above the igniter can surface.

GUNFIRE. Three rocket catapult units were hit with 30 caliber gunfire, igniting the sustainer grains. The motor tube of two units ruptured without being propulsive. The third unit also ruptured, but it separated from the launcher tube and traveled 600 yards reaching an altitude of 200 feet.

BONFIRE. One rocket catapult unit was placed in a bonfire of fuel oil and wood. After 2 minutes and 15 seconds the unit exploded but was not propulsive.

FUEL LEAK. Two rocket catapult units were fired to determine the effect of rocket blast with a damaged (leaking) fuel cell located directly behind the cockpit bulkhead. The units fired normally with no resultant fuel ignition.

FULLY RESTRAINED FIRING. The rocket catapult unit was fired with the rocket motor fully restrained in the launcher. The breech pressure increased to 2,750 psi at which time the sustainer grain ignited and the breech can was blown through the launcher breech. The rocket motor burned normally, exhausting through the ruptured breech.

Environment

TRANSPORTATION VIBRATION. Early vibration studies showed design weaknesses in piston action and piston bar damage to the primary igniter. Two steel shear screws were necessary to hold the slider valve in place. Correct dimensioning of the slider valve and piston was necessary to prevent leakage near the O-rings, which would cause preignition. These areas were redesigned and vibrated in accordance with the transportation vibration schedule of Specification MIL-E-5272 (ASG) Environmental Testing, Aeronautical and Associated Equipment, General Specification for. No defects were observed.

Four units were loaded and packed in Mk 217 Mod 0 shipping containers and vibrated in accordance with the transportation schedule. The units were removed from the shipping containers and unloaded. No defects were observed.

AIRCRAFT VIBRATION. Four units were subjected to aircraft vibration tests in accordance with Procedure XII of Specification MIL-E-5272. All four units were vibrated 1 1/2 hours at 70°F. The four units were vibrated an additional 1 1/2 hours; three at 0°F and one at -65°F. The unit vibrated at -65°F was fired at that temperature successfully. The units vibrated at 0°F were fired at 165°F; two units functioned normally and one malfunctioned. The malfunction was not attributed to vibration; the cable ball sheared from the cable before valve piston actuation. This failure was corrected by increasing the ball shank area.

SAND AND DUST. Six rocket catapult units were loaded and subjected to sand and dust tests at ambient temperature in accordance with Procedure I of Specification MIL-E-5272. One unit was unloaded for inspection and was free of dust inside the firing mechanism and the launcher breech and tube. The other five units were fired successfully at -65°F.

SALT SPRAY. Six rocket catapult units were subjected to salt-laden air spray for 48 hours. Three units were removed from the spray; one unit was packed wet for firing and two units were permitted to dry for 24 hours for inspection per Specification MIL-E-5272. The remaining three units were subjected to the spray for 96 hours; one unit was packed wet for firing and two units permitted to dry for 24 hours for inspection per Specification MIL-E-5272.

The six units functioned normally when fired statically as follows:

1. The two wet units were fired at 70°F.

2. Two units, one treated for 48 hours and one treated for 96 hours, were fired at -65°F.

3. The two remaining units were fired at 165°F.

THERMAL SHOCK. A rocket catapult unit was installed in an A4D cockpit at -65°F. The cockpit air conditioning raised the temperature to 70°F. The unit was unloaded and no grain fracture was detected.

TEST FIRING

Test Equipment

FREE-FLIGHT TEST STAND. The free-flight test stand (Fig. 15) was weighted to 340 pounds to simulate the man-seat mass to be ejected. The tests were instrumented with telemetering equipment and accelerations were recorded by oscillograph. Using a 45-degree nozzle, heights of 250 feet were obtained with the line of thrust approximately 0.5 inch below the center of gravity. The parachute used was a 28-foot, flat canopy, chest-type unit actuated by a mechanical timer set to function 2.8 seconds after catapult ignition.

Test results showed that onset rates were 350 g/sec with maximum acceleration of 16 g. During the development program, these results were reduced to 250 g/sec with a maximum acceleration of 12 g, which is within the physiological limits of the human body.

STATIC TEST STAND. The static test stand (Fig. 16) was developed to simulate the action of an aircraft seat being launched. Breech and motor pressures are recorded by oscillograph. Standard firing mechanisms and launcher breech cans may be modified to record these pressures. Vertical and horizontal thrust components, created by the 45-degree nozzle, are also recorded. A 9-inch-diameter metal weight, simulating the man-seat mass, is braked by the resistance of compressed air. Braking action is controlled by the brake cylinder vent. Booster and sustainer parameter limits are established in the Rocket Loaded Assembly Specifications.[2] The booster and sustainer parameters measured are:

1. Booster and sustainer ignition delay.
2. Rate of booster pressure rise in the launcher tube.
3. Booster launch time.
4. Sustainer action time.
5. Booster and sustainer early maximum pressures.
6. Booster and sustainer pressure - time integrals.

Test Firings

Prototype rocket catapult units with the original grain were fired over the temperature range of -65 to 165°F. Unsatisfactory results

[2] U. S. Naval Ordnance Test Station. Loaded Assembly Specifications for the Rocket, Aircraft Ejection Seat, Catapult Mk 1 Mod 0. (NOTS XS-170), UNCLASSIFIED.

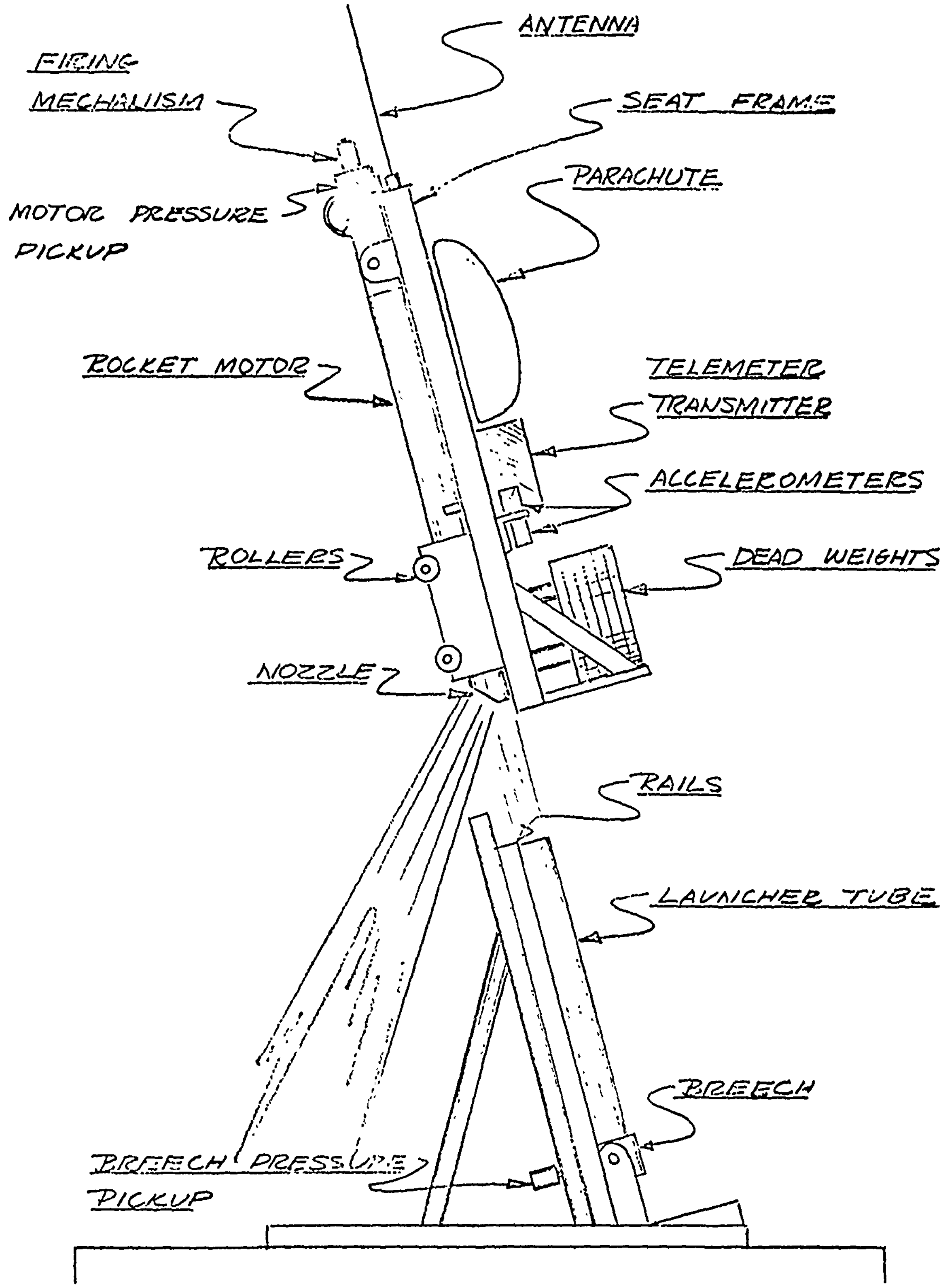

FIG. 15. Free-Flight Test Stand.

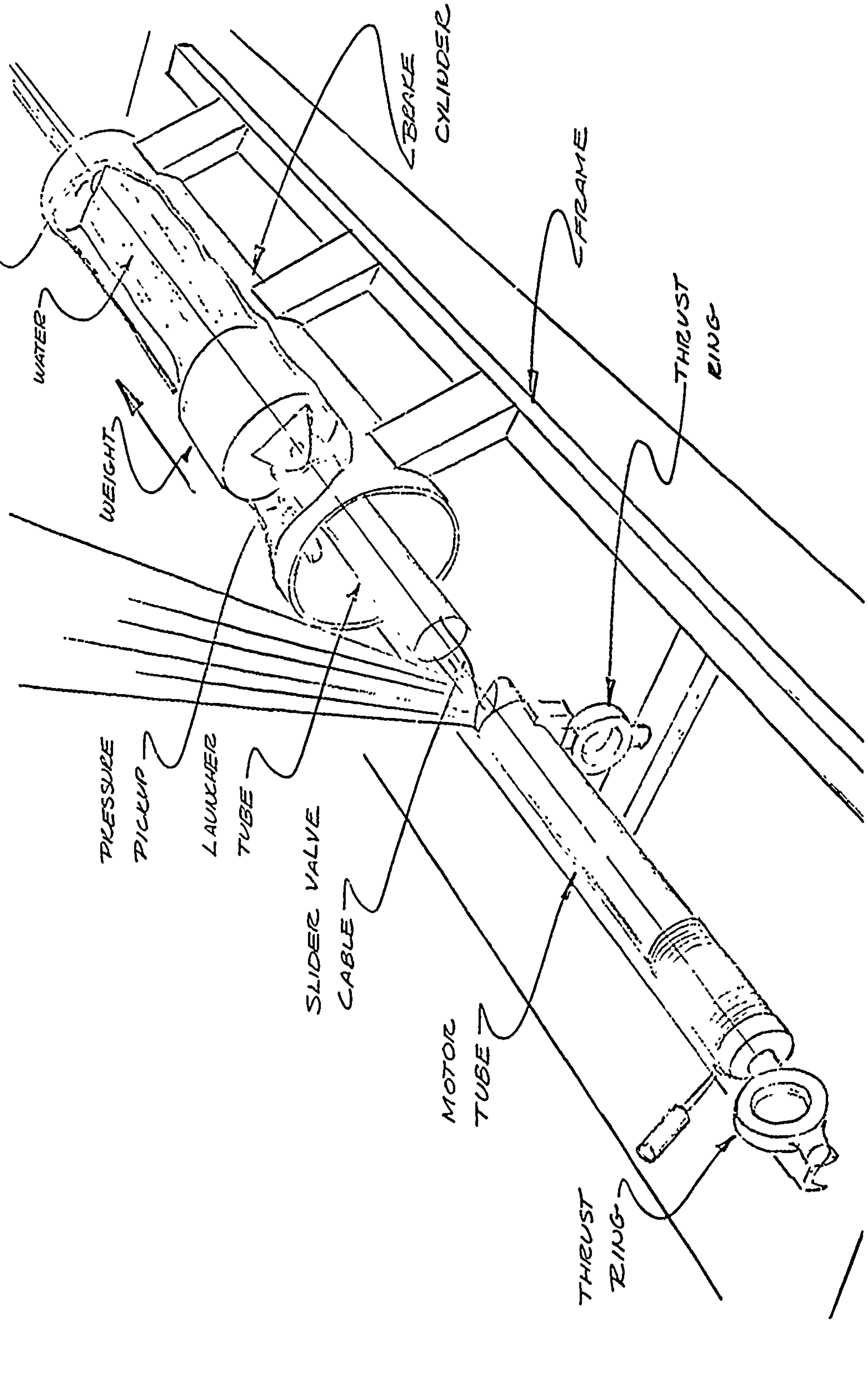

FIG. 16. Static Test Stand.

were obtained with an experimental machined grain designed to reduce grain cracking; no further consideration was given to this design.

A high sustainer early maximum pressure (EMP) condition was encountered in several firings at -65°F. Process studies had shown that the port area of the sustainer grain decreases with age, which further aggravates the high EMP condition; therefore, the grain design was modified to increase the port area from 1.84 to 1.87 in^2. Further development included replacement of the 1 by 9 cable with a 1 by 7 cable, and reduction of excessive igniter delay by increasing the auxiliary igniter charge weight from 4.0 to 4.3 grams. The internal ballistics were not changed significantly in any of these firings.

A series of test firings of a design incorporating the modified grain perforation produced no gross malfunctions over the temperature range of -65 to 165°F. Performance improvements during this series of tests resulted from the following design changes:

1. Reduction of high EMP, attributed to a cracked grain (at -65°F) and to the 0.030-inch floating grain disk, by designing a fixed collar and additionally counterboring the head end of the sustainer grain. This modification provided a fix for the floating disk and aided in reducing grain cracking at -65°F.

2. Reduction of excessive ignition delays at -65°F by increasing the outside diameter of the fixed collar so as to trap more of the auxiliary igniter flame. This reduced ignition delay at -65°F without increasing EMP at 165°F.

Final static tests of the rocket catapult units, using the Mk 106 Mod 0 primer, produced normal motor firings with no gross malfunctions.

During a series of static-dynamic tests, two malfunctions occurred; the sustainer grain was pre-ignited, and the valve piston was not actuated. The preignition of the sustainer grain, caused by a gas leak at the valve piston, was corrected by increasing the piston size to 0.934-inch OD. The valve piston was not actuated because the cable was cut as it passed over the nozzle port. A 0.187 by 0.220-inch slot was machined in the nozzle to provide for cable travel.

The final static-dynamic tests were conducted with the rocket catapult unit pushing a weight, equal to the man-seat mass, down a track. This subjected the motor to normal accelerations experienced in actual operation. No gross malfunctions occurred; in 32 firings at -65°F one cracked grain caused a high EMP. The cracked grain was not considered a problem, inasmuch as the probability of firing a catapult at -65°F is remote and the motor is designed to withstand 7000 psi (the pressure generated by a cracked grain is approximately 5000 psi).

A4D Qualification Test Program

The Douglas Aircraft Co., in conjunction with NOTS, outlined a test program to qualify the Mk 1 Mod 0 rocket catapult for use in A4D aircraft. The program consisted of a series of functional, structural, environmental, and static and dynamic ejection tests.

An A4D aircraft seat, modified to accommodate the Mk 1 Mod 0 Rocket Catapult and Alderson C-5 and C-95 anthropomorphic dummies, was used for preliminary static firing and sled tests.

Later in the program, Model P-2-5 (5th percentile) and Model P-2-95 (95th percentile) dummies were used to represent men weighing 134 and 200 pounds, respectively.

During the following test program, the Mk 1 Mod 0 functioned normally, except as noted, through the complete ejection sequence (Fig. 17).

1. A series of four slow-speed, ground-level ejections at 90 knots indicated air speed (IAS) from an unmanned airplane, catapulted down the runway by a steam catapult. The tests were conducted by the Aircrew Equipment Laboratory, Philadelphia, Pa.

2. A series of thirteen low- and high-speed sled runs (90 to 6C knots IAS). These tests were conducted at the NOTS Supersonic Naval Ordnance Research Track (SNORT).

During the high-speed sled runs, three malfunctions occurred. The malfunctions and resultant corrective actions were

1. At 500 knots IAS, the valve piston was not actuated because the cable ball sheared. The shank (surface area) of the ball on the cable was increased and the test acceptance pull was increased from 2000 to 2,500 pounds.

2. At 600 knots IAS, the firing pin failed to strike the primer because of a burr on the firing pin. A 100% functional inspection of the firing mechanism is now part of the loading instructions.

3. At 600 knots IAS, a faulty motor tube caused the rocket nozzle to separate from the motor tube. Motor tubes that met the requirement of a 125,000-psi yield were procured from a different manufacturer; the tubes now used will withstand 7,000 psi before failure.

Subsequent modification of the grain design achieved a reduction in EMP of approximately 800 psi at 165°F.

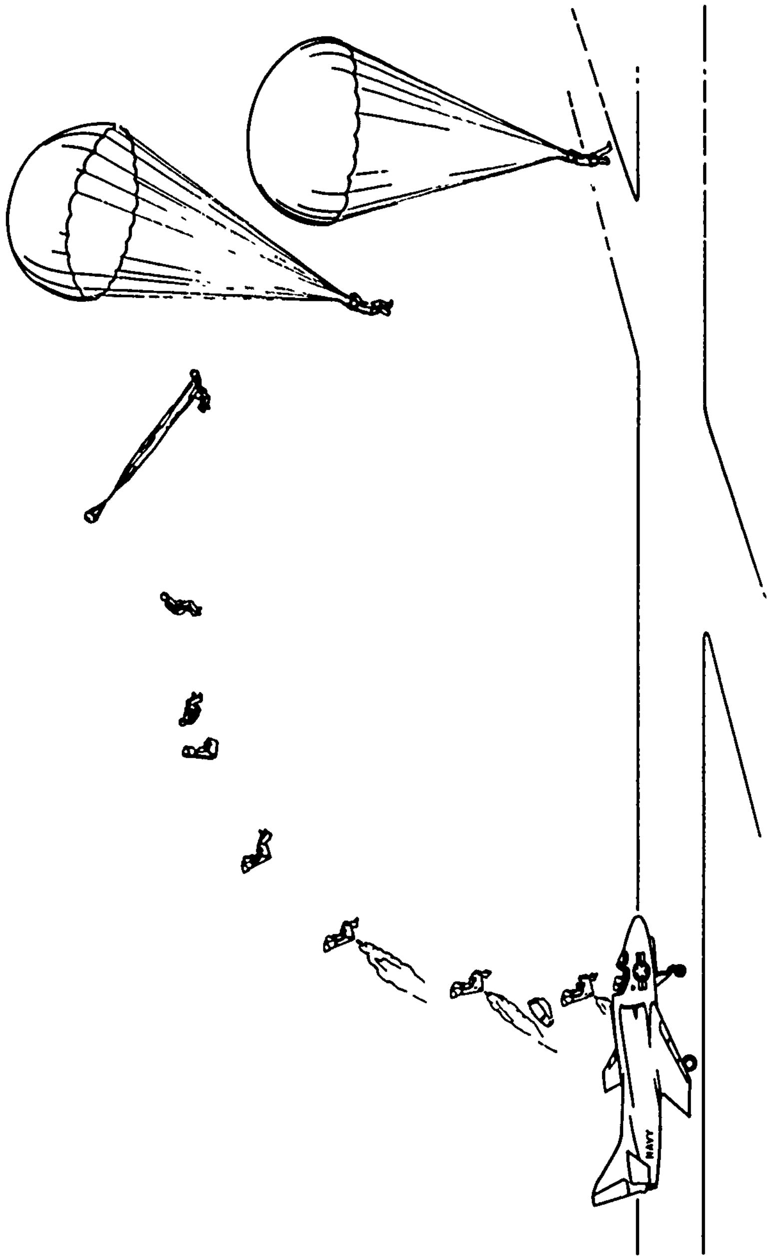

FIG. 17. Rocket Catapult Mk 1 Mod 0 Ejection Sequence.

In-Flight Qualification

Eight in-flight ejections were made from the rear cockpit of a manned, two-seat, test aircraft. The seat and dummy were ejected over an altitude range from ground level to 15, 000 feet. All tests, conducted at the Naval Parachute Facility, El Centro, were successful.

EXPERIMENTAL PRODUCTION

In order to speed up Fleet introduction, the Naval Ordnance Test Station produced and delivered the first 182 production units to Douglas Aircraft Co., El Segundo, Calif., to be installed in A4D aircraft coming off the production line. NOTS production was then transferred to the following facilities:

1. Naval Ammunition Depot, Crane, Indiana. Production of the Mk 189 Mod 0 auxiliary igniter.

2. Naval Propellant Plant, Indian Head, Maryland. Production of the booster charge and the Mk 60 Mod 0 sustainer grain, and loading of the rocket catapult.

3. Naval Ordnance Plant, Macon, Georgia. Production of the Mk 250 Mod 0 rocket igniter.

4. Various private contractors. Production of inert parts.

NOTS preliminary production required various types of test, inspection, loading, and handling and shipping equipment. The following paragraphs list the equipment designed and developed for NOTS production.

Inspection Equipment

Inspection of components is required during the experimental phase, when the purpose of testing is primarily to demonstrate technical soundness of basic ideas. The following items were designed for this purpose:

1. A cable tester designed to test the steel balls on the cable of the propellant strip assembly to withstand a force of 2,500 pounds

2. A thickness gage designed to measure the weakened sections of the booster tube.

3. A pressure tester designed to test a loaded booster tube assembly under pressure.

4. Gages to measure the propellant grain indicated the length, OD, major and minor ID, wall thickness, and bow.

Handling and Loading Equipment

Handling equipment required for grain development and curing includes

1. Drying racks for the propellant strip holder and sustainer grain.

2. Contour racks for grain post curing.

3. Grain processing equipment.

Loading tools were required to ensure reproducibility and reliability. They are as follows:

1. Propellant strip press assembly

2. Propellant strip holder alignment jig

3. Nozzle installation fixture

Detailed information is presented in a NOTS Technical Notice.[3]

SURVEILLANCE PROGRAM

A post-production surveillance program has been initiated by NOTS and the Naval Propellant Plant. The information gained from this program will be the basis for determining the shelf life of the Mk 1 Mod 0 Rocket Catapult now in Fleet use. It will also serve as a basis for establishing environmental conditions that will be imposed on the Mk 2 Mod 0 rocket catapult. The program consists of three phases.

Phase I - Type Life

Units are subjected to simulated Fleet conditions and inspected physically and ballistically at intervals. This phase will be conducted at the Naval Propellant Plant.

[3] U. S. Naval Ordnance Test Station. Rocket-Assisted Personnel-Ejection Catapult NOTS Model 103B, Progress Report for Fiscal Year 1959, by J. C. Metcalf. China Lake, Calif., NOTS, 1 August 1959. (NOTS TN IDP 685), UNCLASSIFIED.

Phase II - Fleet Return

Units are removed from Fleet aircraft and inspected physically and ballistically. This phase will be conducted at the Naval Propellant Plant.

Phase III - Maximum Environment

A series of cockpit environmental tests was conducted on three rocket catapult units to check temperature parameters. Since the rocket catapult had not been subjected to environmental conditions exceeding the -65 to 165°F range, it became essential to investigate possible maximum and minimum temperatures to which the unit would be subjected during extreme operational conditions.

HOT WEATHER TEST. Two Mk 1 Mod 0 rocket catapult units were installed in identical A4D cockpit installations. One cockpit was set up at NOTS; the other cockpit at the Naval Parachute Facility (NPF), El Centro, California.

The maximum canopy and cockpit temperatures recorded on the hottest day, during the three-month test cycle, are shown in Fig. 18. A maximum rocket catapult temperature of 181°F was recorded on the top 1 1/2 inches of the unit. This area receives direct radiant heating from the sun; the rest of the catapult was shielded from the direct rays of the sun by the seat.

Complete procedures, test data, and results have been reported.[4]

COLD WEATHER TEST. Previous tests have shown the Mk 1 Mod 0 and the Mk 2 Mod 0 to be thermodynamically identical; therefore, the Mk 2 Mod 0 was used in this test. The test was conducted at the Army's Ordnance Arctic Test Activity (OATA), Fairbanks, Alaska. The test vehicle was an F9F-6P with the cockpit modified to simulate an F9F-8T two-seat jet trainer.

The minimum canopy and catapult temperatures recorded on the coldest day during the 4-month test cycle are shown in Fig. 18. The minimum catapult temperature of -65°F was recorded on the launcher tube. Only minor temperature variations existed between the top and the bottom of the catapult.

Figure 19 shows the probability of minimum temperatures that occur during the seven winter months in the Fairbanks area, based on 14 years of meteorological records. It can be seen that a -40°F

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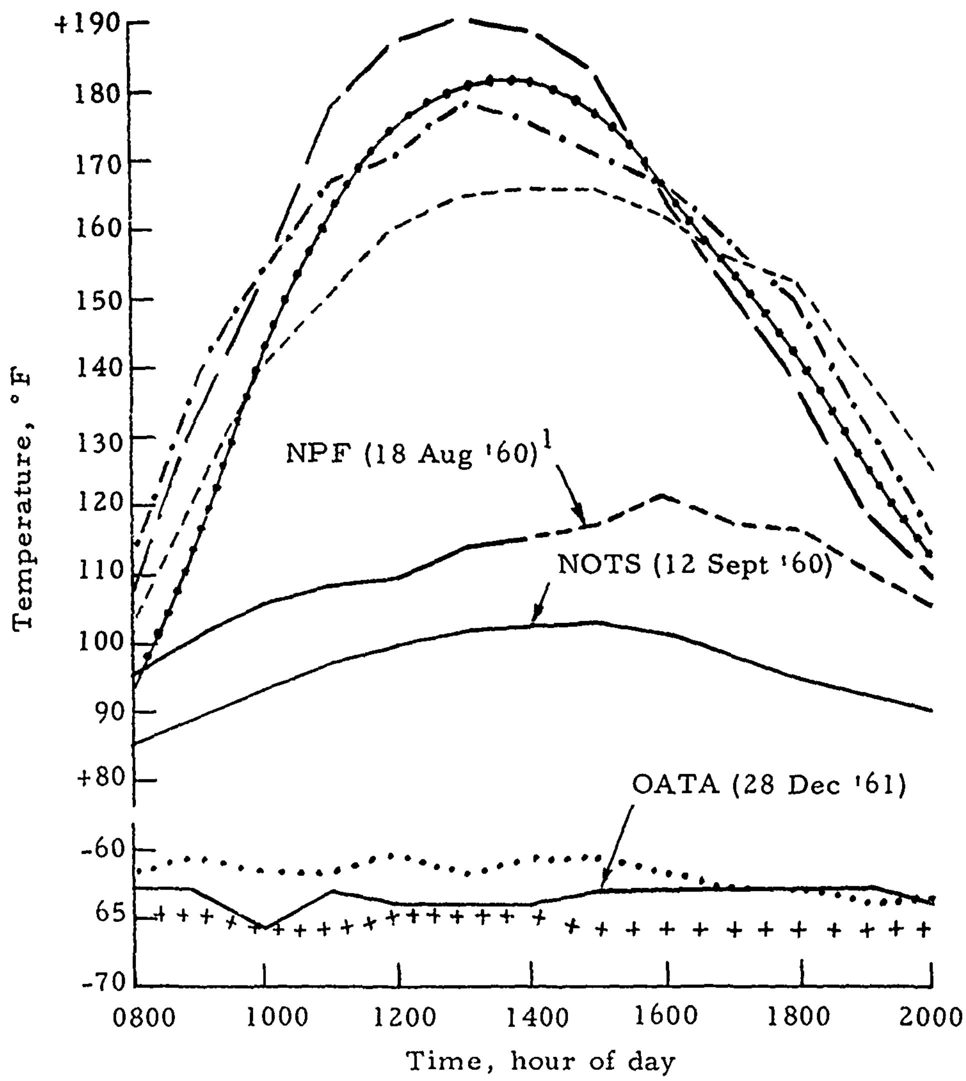
[4] U. S. Naval Ordnance Test Station. Environmental tests of Rocket Catapult Mk 1 Mod 0 (Aircraft Ejection Seat), by Howard Schafer. China Lake, Calif., NOTS, March 1961. (NAVWEPS Report 7631, NOTS TP 2638), UNCLASSIFIED.



Legend

Ambient air temperature
Inside canopy temperature:
NOTS
NPF
OATA

Maximum catapult temperature:
NOTS
NPF
Minimum catapult temperature:
OATA

[1] NPF ambient air recorder failed at 1400 hrs; broken line approximates temperature.

FIG. 18. Maximum Environment Test Results.

temperature has a 5% chance of occurring during the winter months, and a -65° F temperature would seem to have less than a 1% maximum chance of occurring.

Complete procedures, test data, and results of the cold weather test have been reported.[5]

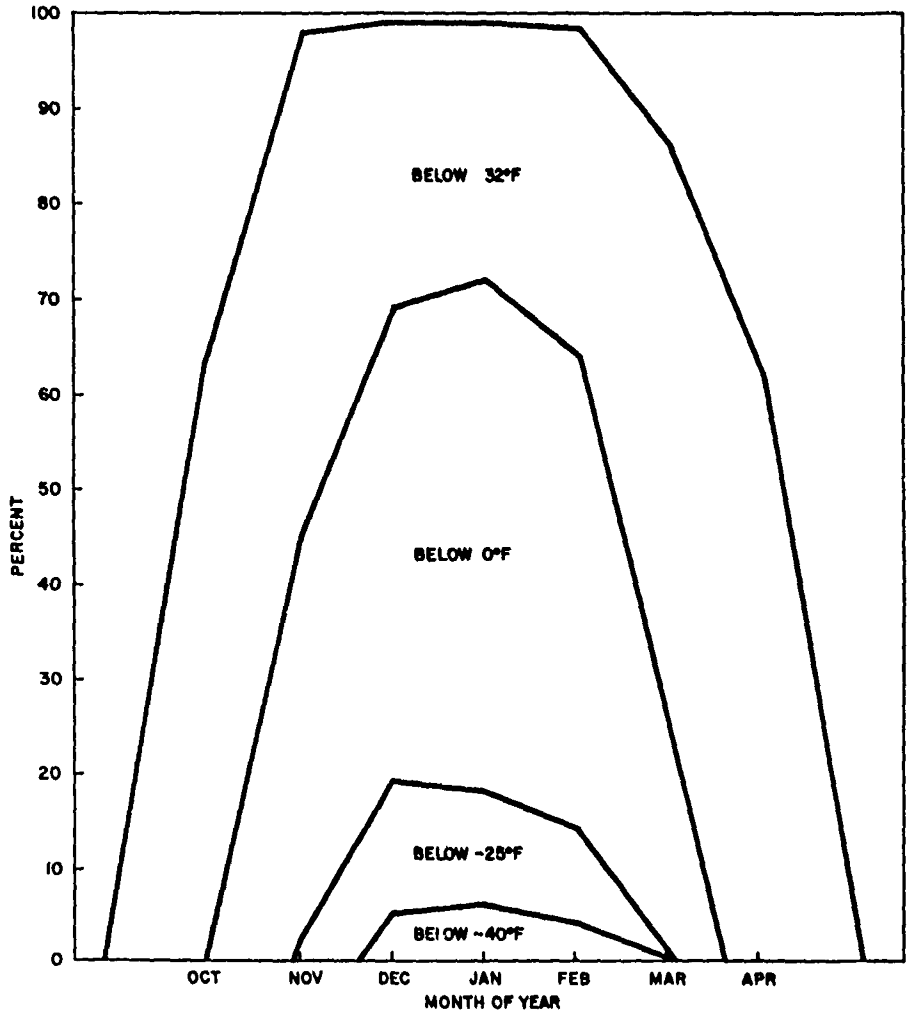


FIG. 19. Percentage of Time Below Specified Temperatures, Fairbanks, Alaska.

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[5] U. S. Naval Ordnance Test Station. Cold-Weather Environmental Tests of Rocket Catapult Mk 2 Mod 0 (Aircraft Ejection Seat), by Howard C. Schafer. China Lake, Calif., NOTS, May 1962. (NAVWEPS Report 7875, NOTS TP 2858), UNCLASSIFIED.

ROCKET CATAPULT MK 2 MOD 0

The Rocket Catapult Mk 2 Mod 0 (Fig. 20) is a self-propelled, mechanically initiated, two-phase, solid-propellant booster and sustainer rocket. It has been designed to eject a maximum man- seat

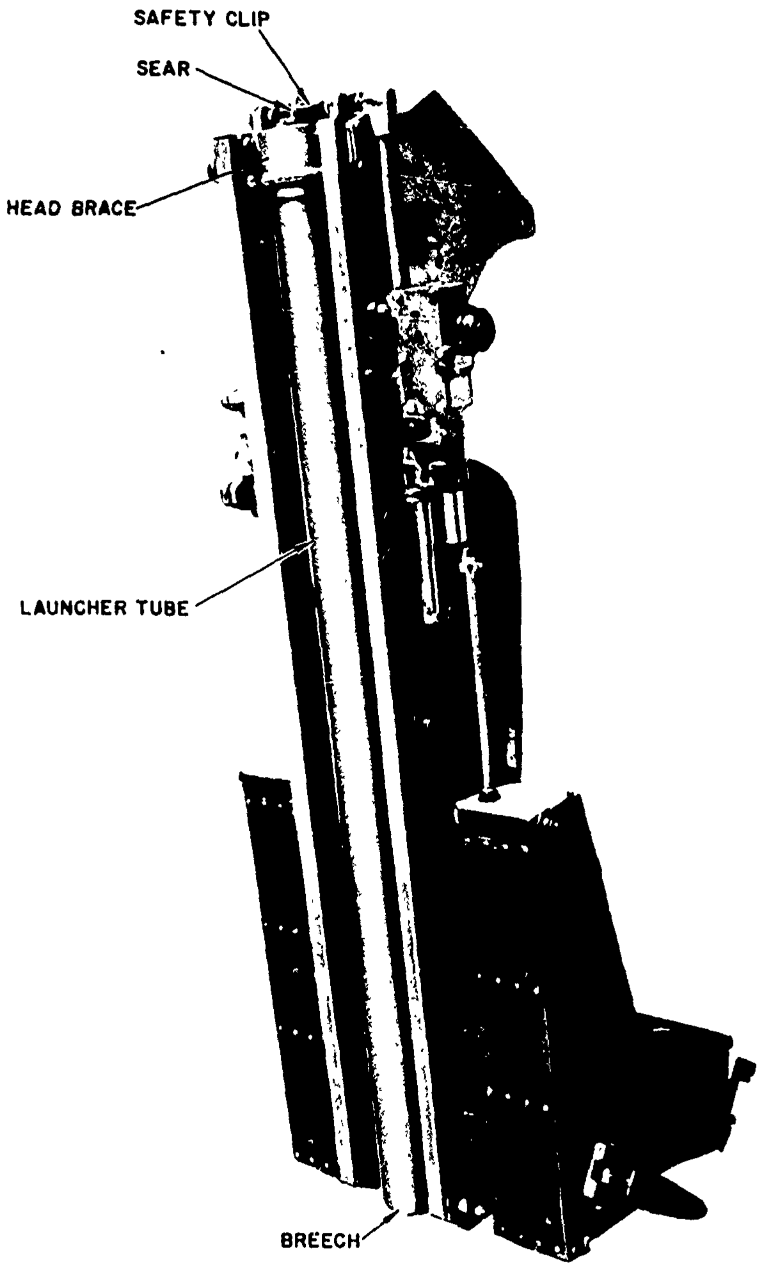


FIG. 20. Rocket Catapult Mk 2 Mod 0 Aircraft Ejection Seat Installation.

mass of 430 lb, at zero velocity and zero altitude, to an altitude sufficient for a parachute to deploy and at accelerations within the physical tolerances of the human body.

The Mk 2 Mod 0 is an advanced version of the Mk 1 Mod 0 and is similar in design. The major design differences are the booster assembly, which provides more accurate control of the onset rate and total g's during the booster phase, and a new launcher tube which is a load-carrying member.

The Mk 2 Mod 0 has been designed to replace the Martin-Baker Catapult gun in all Martin-Baker seat systems, requiring only minor metal parts modification and nozzle angle change. Initial installation with the present 36° 12' nozzle will be in the A2F, F4H, and F8U aircraft. The altitude performance of the Mk 2 Mod 0 exceeds the performance of the Martin-Baker gun by a factor of three while subjecting the pilot to a considerably lower g load and onset rate.

The length of the Mk 2 Mod 0 is 50 inches, with a diameter of 3 inches. Loaded, it weighs approximately 35 pounds. Figure 21 is a cutaway view of the unit.

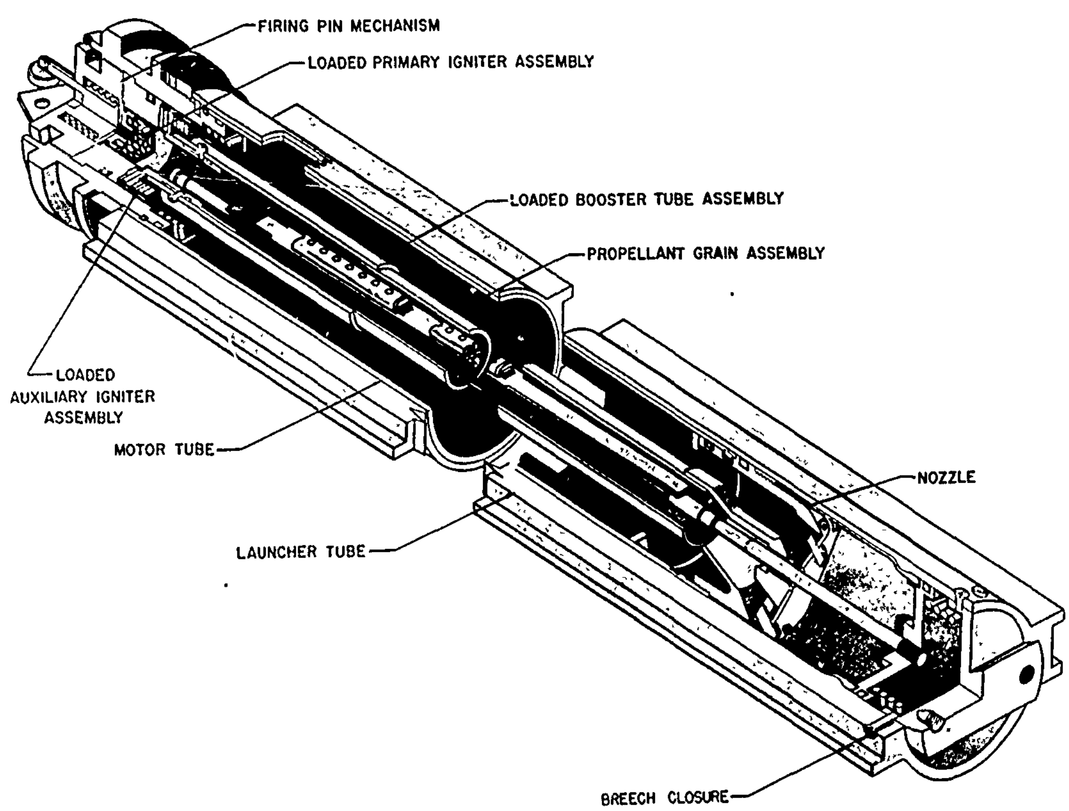


FIG. 21. Cutaway View of Rocket Catapult Mk 2 Mod 0.

Table 4 lists the Bureau of Naval Weapons requirements to which the rocket catapult was successfully developed, qualified, and released for production.

TABLE 4. Bureau of Naval Weapons Design Requirements for the Rocket Catapult Mk 2 Mod 0

Fit Martin-Baker envelope	Length-diameter
Acceleration (max.), g	18
Onset rate of acceleration (max. over any 30 ms), g/sec	250
Firing temperature limits, deg F	-65 to 165
Useful life (shelf and service), years	3
Ejection speed (max.)	Mach 0.98
Ejection altitude (min.), ft	under 30 feet of water
Impact loading (axial), g	40
Probability of gross malfunction	0.0001

The Mk 2 Mod 0 was documented and released for pilot production in December 1961. Table 5 lists the assemblies and their Mk and Mod number.

TABLE 5. Mk 2 Mod 0 Assemblies

Assembly	Mk and Mod No.
Loaded	Mk 2 Mod 0
Propellant grain	Mk 69 Mod 0
Primary igniter	Mk 196 Mod 0
Auxiliary igniter	Mk 195 Mod 0
Firing mechanism	Mk 29 Mod 0
Shipping container	Mk 269 Mod 0

The Mk 2 consists of a booster phase acting as a gas generator to provide a metered amount of gas into the free volume of the launcher breech to boost the man-seat mass out of the aircraft. The sustainer phase is mechanically initiated as the rocket motor clears the launcher tube and pushes the man-seat mass to a sufficient altitude for man-seat separation and parachute deployment. Figure 22 shows typical thrust and acceleration curves developed by the Mk 2 Mod 0.

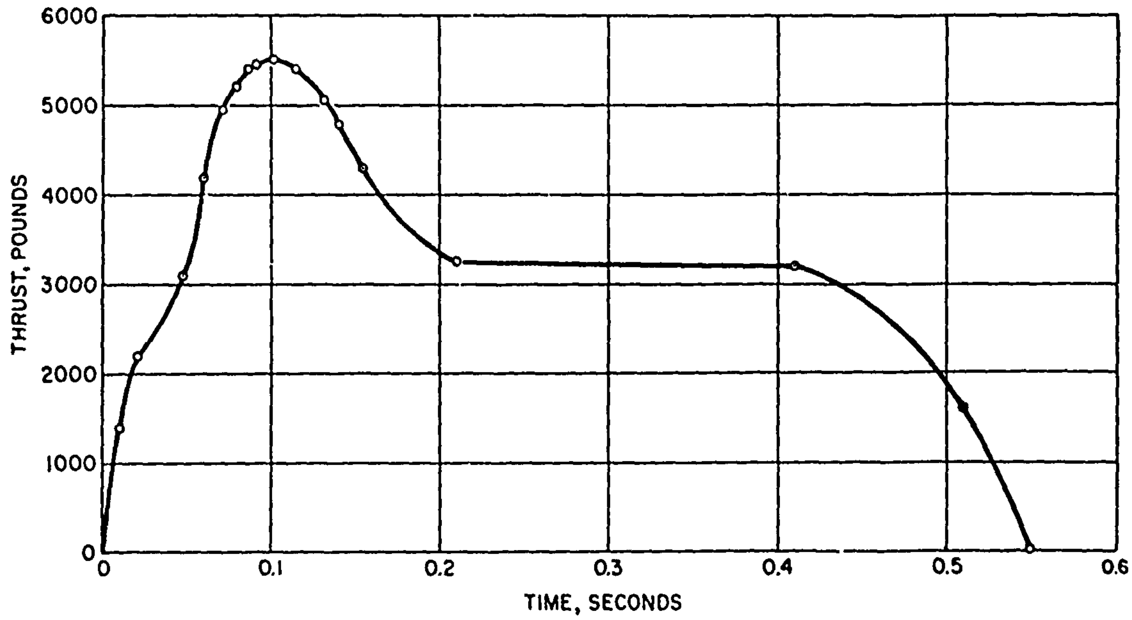


FIG. 22. Typical Thrust - Time Curve, Mk 2 Mod 0.

DEVELOPMENT

Because of the similarity of the Mk 2 Mod 0 to the Mk 1 Mod 0, many Mk 1 Mod 0 design concepts were adopted, some with only minor changes. Two major areas of development, the booster assembly and the launcher tube, are covered in this report, in addition to the other components of the Mk 2 Mod 0 catapult.

Firing Mechanism

The Mk 29 Mod 0 rocket firing mechanism (Fig. 23) is a mechanically actuated device containing a spring-loaded firing pin. When the sear is pulled the firing pin is driven down by a spring and strikes the primer of the primary igniter. A pin and roller allow free movement of the firing pin on the inclined surface of the sear before release. The firing pin contains an O-ring seal that maintains a sealed ignition system. The primer support disk retains the primer in the igniter lid, eliminating the source of hot gas flow into the firing mechanism.

The Mk 29 firing mechanism body is made of aluminum and the firing pin is made of stainless steel. The sear is made of stainless steel because experience in the Fleet with the Mk 1 catapult showed that

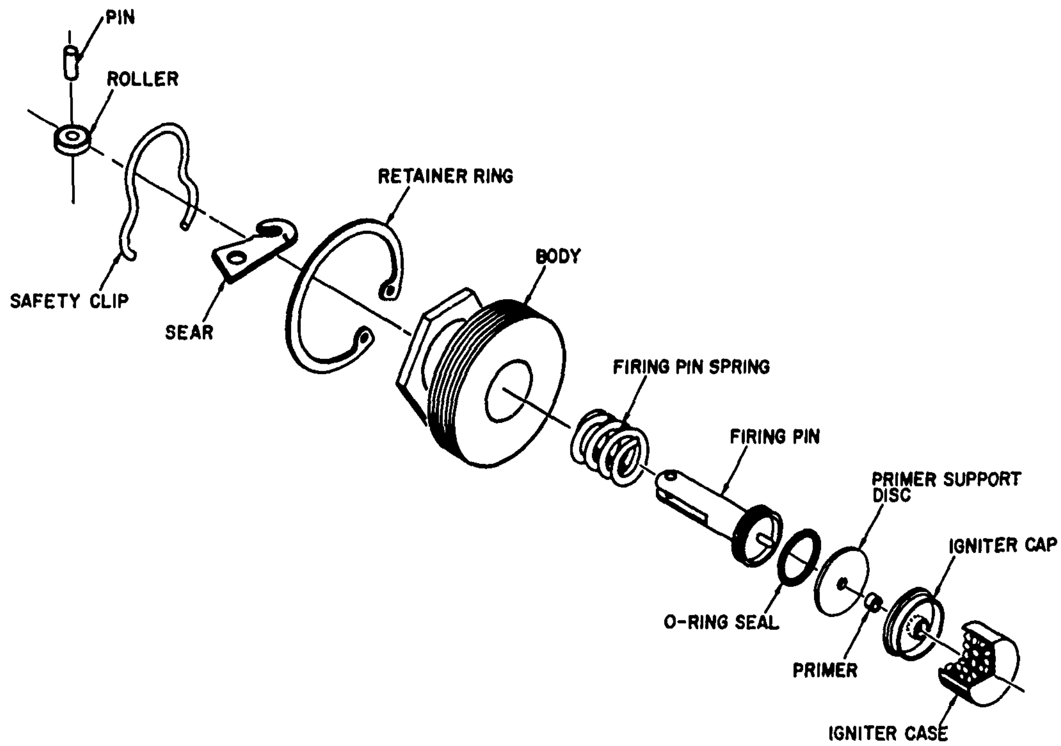


FIG. 23. Firing Mechanism Mk 29 Mod 0.

continual removal and reinsertion of the safety clip wore off the protective coating on the firing mechanism body.

Primary Igniter

Initially, the Mk 1 Mod 0 igniter configuration and charge weight was used for the Mk 2 Mod 0 catapult. Because of booster assembly redesign, the booster charge could not be ignited at -65° F by the 4.5-gram charge weight. The basic igniter design was retained but the can was made deeper to accommodate the additional charge.

The Rocket Motor Igniter Mk 196 Mod 0 (Fig. 24) is used in the Mk 2 Mod 0 catapult. The Mk 196 consists of the Mk 106 Mod 1 primer pressed into an aluminum cover, which is crimped to an aluminum pillbox containing 7 grams of boron potassium nitrate 2R pellets.

During the qualification program static tests, two catapults misfired due to head-end burn-through. It was found that the booster or sustainer pressure was forcing the primer out of the igniter allowing

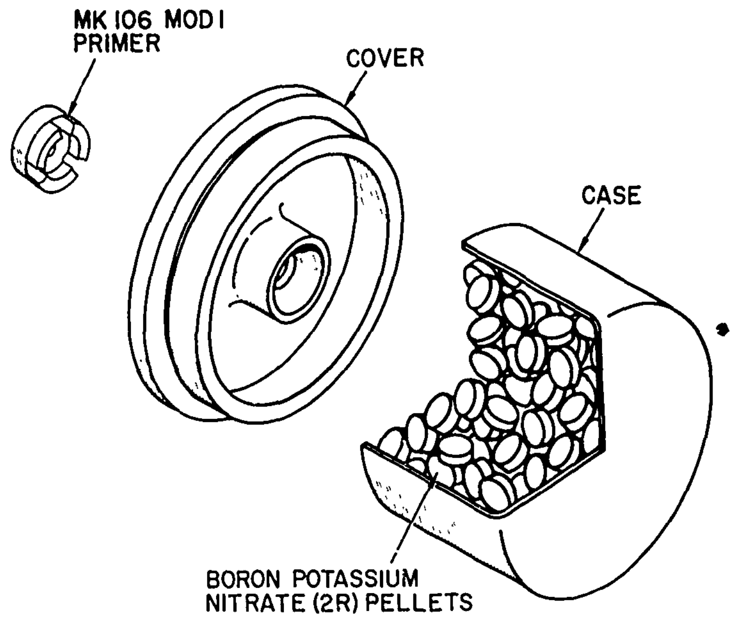


FIG. 24. Rocket Motor Igniter Mk 196 Mod 0.

hot gas to flow into the head. A steel primer support disk, 0.140-inch thick by 1.150 inches in diameter, was designed into the head-end of the booster tube and the firing pin was redesigned to protrude an additional 0.140 inch. This disk retained the primer in the igniter and prevented hot gas from flowing into the firing mechanism.

The igniter assembly was also subjected to vibration shock, temperature and humidity, and firing tests.[6]

Booster Assembly

The original booster design, similar to the Mk 1 Mod 0 design, was discontinued when BuWeps established a lower maximum onset rate of 250 g/sec at 165° F. The redesigned booster assembly (Fig. 25) is the most unique feature of the Mk 2 Mod 0. The purpose of the booster assembly is to provide sufficient gas at the proper rate to control the onset rate and total g's during the booster phase of operation. This phase takes the man-seat mass from the static starting position to the point where the man-seat mass clears the cockpit section. There must be sufficient exit velocity to clear the tail assembly and still remain within physiological limits when the aircraft is traveling at sonic speed. Exit velocity is normally determined to be in excess of

[6] Hi-Ex Corporation. Report Mk 196 Mod 0 (Primary) Igniter Evaluation. Saugus, Calif., Hi-Ex, April 1962. (Contract N60530-7278), UNCLASSIFIED.

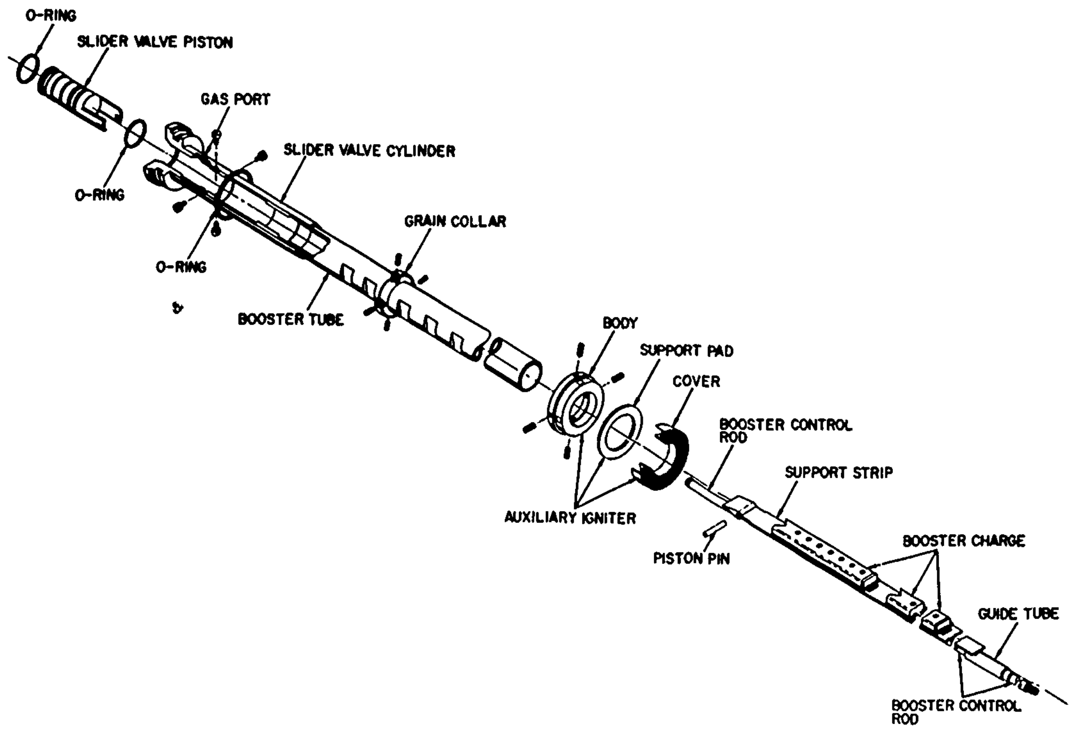


FIG. 25. Booster Assembly.

40 ft/sec. The booster assembly is essentially a gas generator with the booster tube running down the perforation of the sustainer grain. The source of gas in the booster stage is five inhibited high-energy X-12 bar charges, commonly called "candy bars," mounted on a strip holder with silicone tube (Fig. 26). The rate of gas generation is precisely controlled with seven holes through the candy bar and a V-shape at the upper end. The bottom end has an inhibitor to prohibit burning. As the burning progresses and the holes get larger, the burning surface and the rate of gas generation increase as the volume in the breech increases, due to the rocket catapult being forced up the launcher by the gas.

On the side of the strip holder opposite the candy bars is the control rod. The control rod supplements the onset rate control by metering the proper amount of gas into the breech. Figure 27 shows how the control rod is initially fed through the nozzle and secured to the can breech. Also shown is the enlarged end at the top of the control rod, which ultimately will lodge and pull the strip holder as it engages the control rod guide to initiate the sustainer phase. At this point in the operation, the control rod breaks at a necked-down section with the control rod top sealing the nozzle booster orifice and the long portion of the rod remaining in the launcher tube.

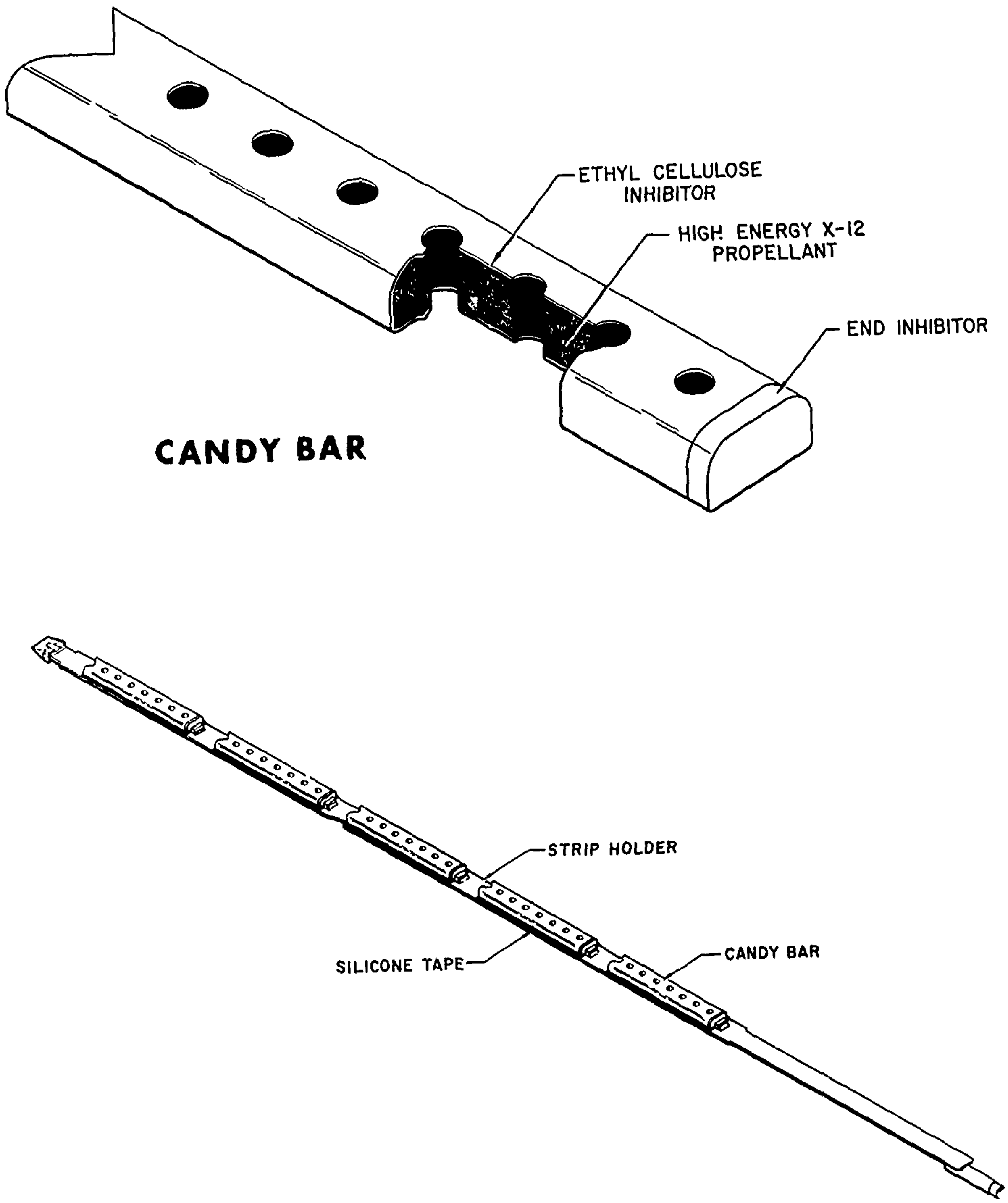


FIG. 26. Booster Strip Assembly.

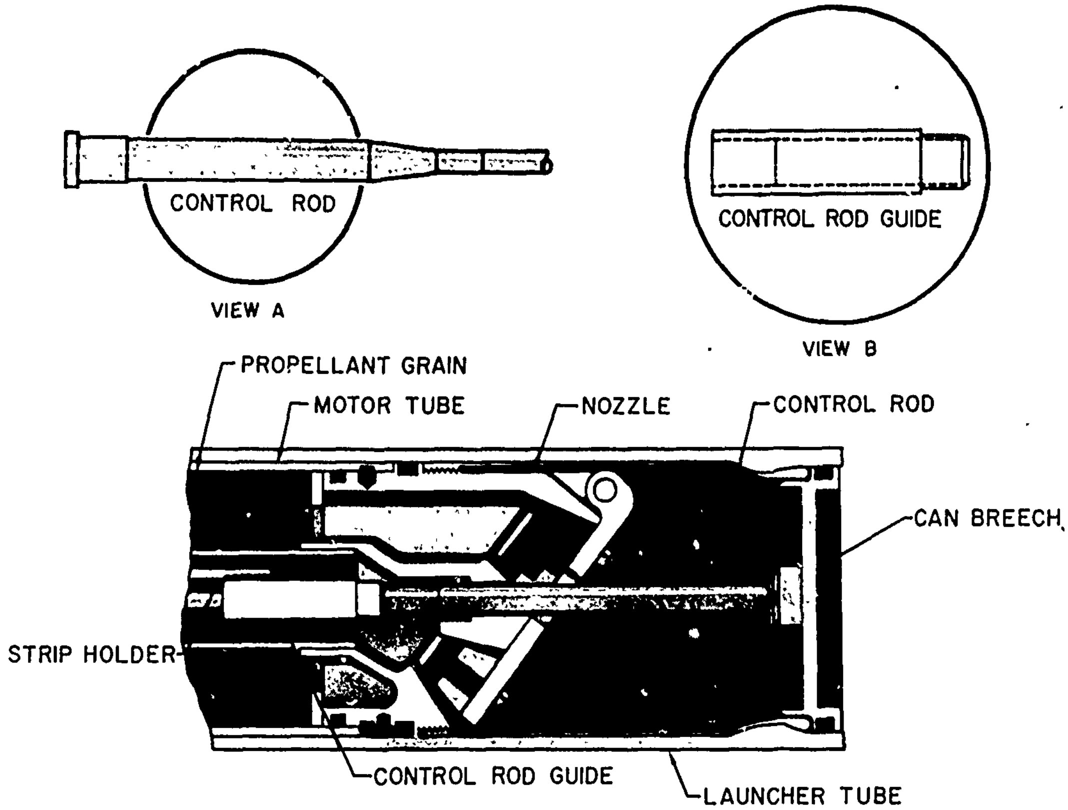


FIG. 27. Launcher Breech and Control Rod.

The control rod has numerous tapers providing a variable cross sectional orifice area metering the flow of hot gases into the breech volume. Figure 28 shows how the control rod tapers and how the different diameters influence the pressure-time curves relative to these positions.

When the booster assembly is complete, the strip holder is secured inside the booster tube by attaching it to the slider valve piston. The piston is actuated and opens the gas ports upon full-length travel of the control rod, which occurs as the rocket is leaving the launcher tube. Hot booster gases flow out of the booster tube through the gas ports and into the rocket motor igniting the auxiliary igniter and, subsequently, the sustainer grain.

A grain collar is secured around the booster tube, allowing pressure build-up above the collar and ensuring grain ignition at low temperatures. The booster tube has five flats milled to 0.022 inch in thickness to allow burn-through of the sustainer gases into the booster tube to equalize pressures and prevent collapse of the booster tube during normal

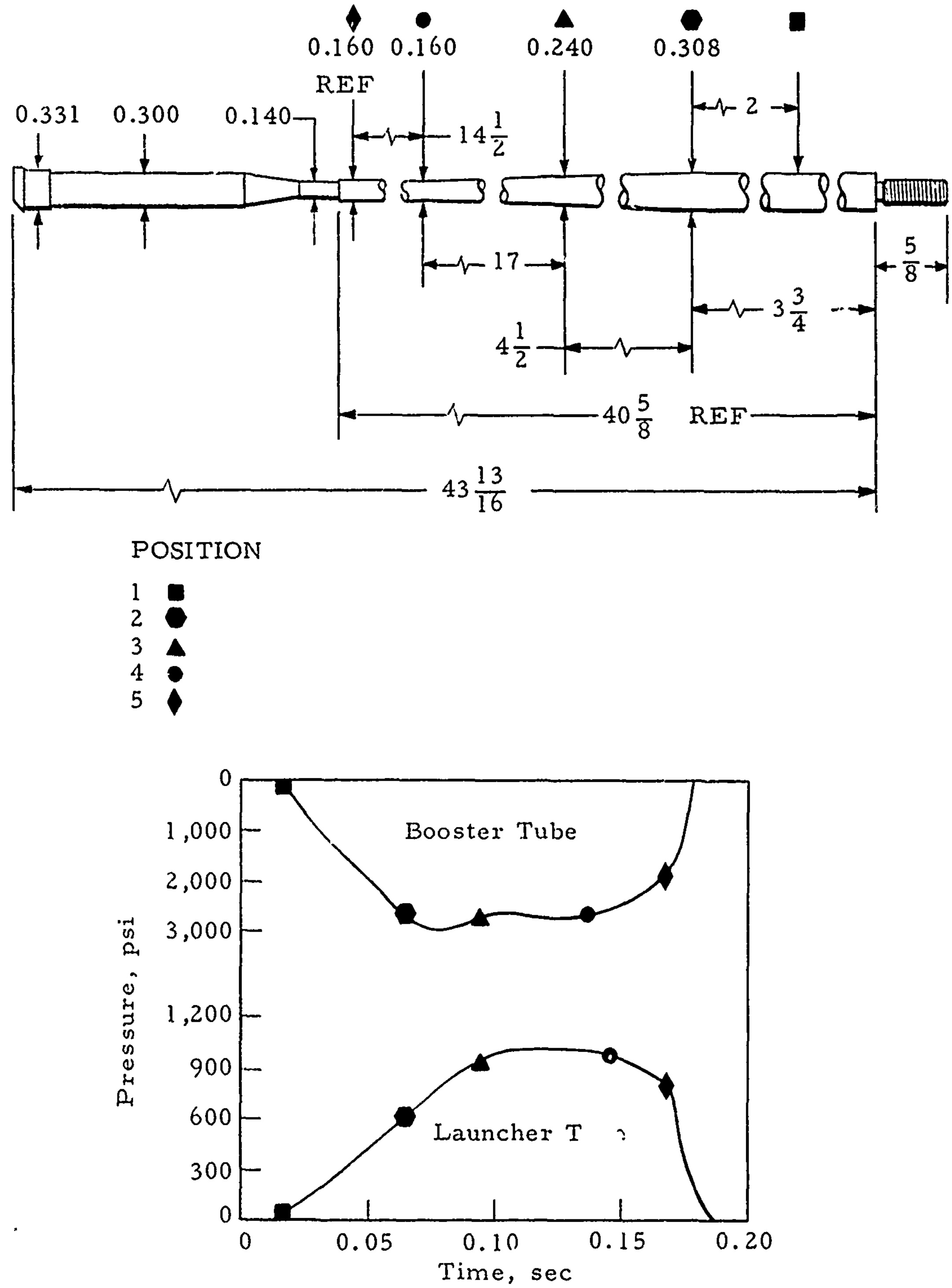


FIG. 28. Control Rod Influence on Tube Pressures.

sustainer phase operation. Gases flow through the booster tube and out a nozzle port. By this method, the maximum utilization of area on the nozzle face is realized.

Auxiliary Igniter

The auxiliary igniter is designated Rocket Motor Igniter Mk 195 Mod 0 (Fig. 29). Seven grams of 2R zirconium lead dioxide pellets are contained in a vented cover, which readily allows the hot booster gases to flow over the pellets. The pellets rest on a support pad and are secured to an aluminum body which fits over the booster tube. The body is secured by set screws to the booster tube.

Sustainer Motor Assembly

The sustainer motor assembly (Fig. 30) consists of the entire sustainer phase of the two-stage rocket catapult. The increased burn time and thrust provide additional altitude and give the system zero altitude, zero speed capability. The burn time of the sustainer motor is 350 ms. Nominal thrust at 70° F is 3,540 pounds as measured along the line of thrust (not along the centerline of the catapult).

The Sustainer Grain Mk 69 Mod 0 is 37 inches long, 2.6 inches in diameter, and weighs 6.43 pounds with inhibitor, with a perforation as shown in Detail A of Fig. 30. The propellant is high-energy X-12 and is identical in cross section to that used in the Mk 1 Mod 0. The propellant grain is supported by a grain spring inside the 4130 steel

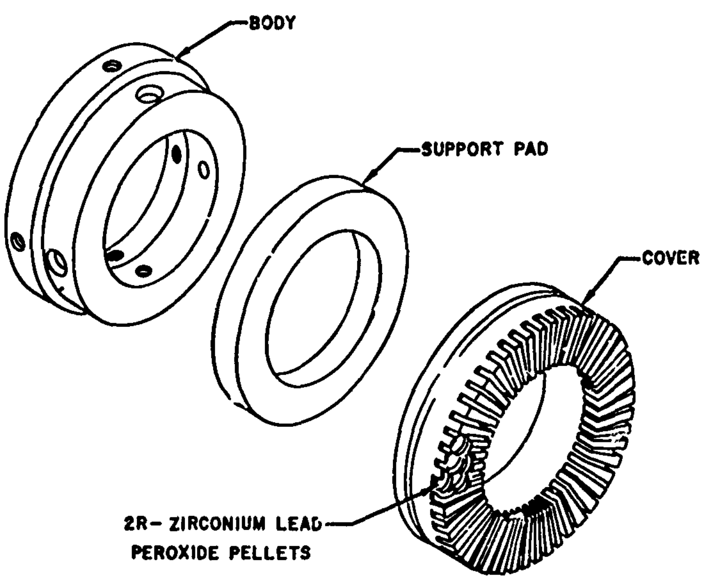
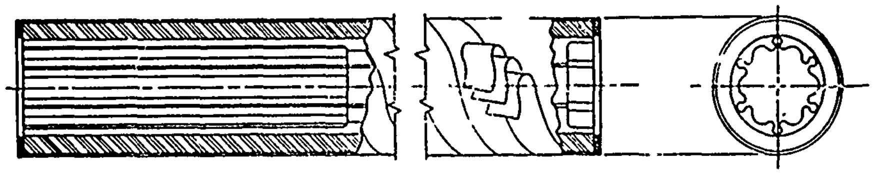


FIG. 29. Rocket Motor Igniter Mk 195 Mod 0.



Detail A

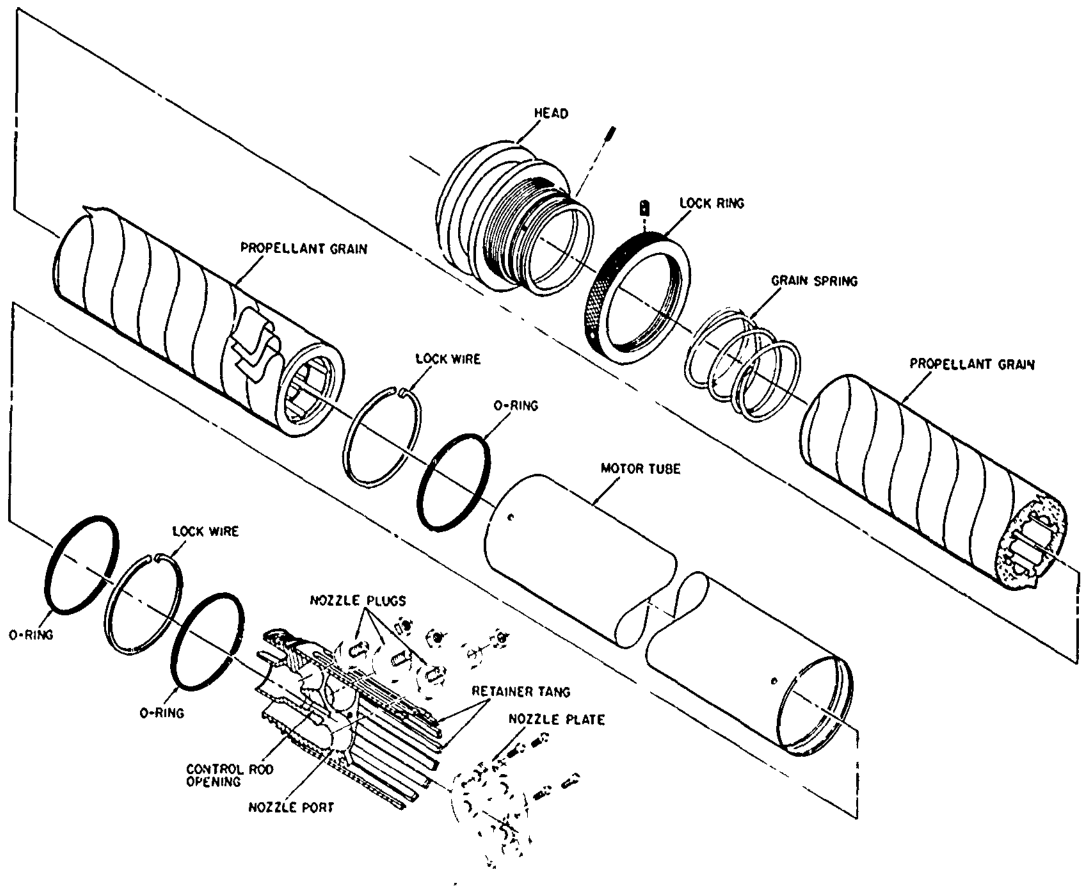


FIG. 30. Sustainer Motor Assembly.

motor tube. The top closure of the motor tube is an aluminum head, which is lock wired and sealed by an O-ring. The head contains the Mk 29 firing mechanism. The aft end of the motor tube is closed by a multiport nozzle, which is also lock wired and O-ring sealed into the motor tube.

The four port nozzle is cast from mild steel and has an angle of 36° 12'. This provides the proper angle of thrust for use in the A2F, F4H, and F8U aircraft.

Late in the development program, the Bureau of Naval Weapons requested that ejecta from the rocket catapult be kept to a minimum. Before that time, the nozzle plate attachment, screws, and nozzle plugs were blown free as the motor cleared the launch tube. The redesign hinges the nozzle plate to the nozzle shown in the open position in Fig. 31. The nozzle plugs are contained on the nozzle plate, as are the four shear screws, which are safety wired to the nozzle plugs. The nozzle plate is designed to release at 1,700 psi, although it is difficult to estimate the effects of breech gases and the rate of gas release on the nozzle plate. Consequently, in multiple-passenger aircraft, such as the A2F and F4H, there will be limited ejecta. Threaded onto the nozzle are retaining tangs, which secure the entire rocket motor assembly in the launcher tube assembly.

Launcher Tube Assembly

The launcher tube was designed to fit into the same envelope and withstand the same loading as the Martin-Baker steel cartridge tube. The dynamic loads on the launcher tube are severe, especially during an underwater ejection. The Martin-Baker seat is supported in the aircraft by the launcher tube only. This results in about a 10-inch misalignment between the center of gravity of the man-seat mass and centerline of the catapult. In essence, the load is cantilevered from the launcher tube. In a flooded cockpit, the hydrodynamic forces and lap loads cause an increased overturning movement and high stresses on the launcher tube as the four slippers of the seat move up the rails. Additional adverse loads are imposed on the launcher tube as the pilot ejects through the plexiglass canopy and radiation shield.

Early in the development program it was determined that the launcher tube would be aluminum and could be formed by the cold-extrusion process. During the time required to develop this process, launcher tubes, without launching rails, and complete hot-extruded tubes were obtained so as not to curtail the initial development of the rocket catapult.

When it became apparent that the cold extrusion process could not be demonstrated before design release, alternate methods were investigated and experimental launcher tubes were produced. The

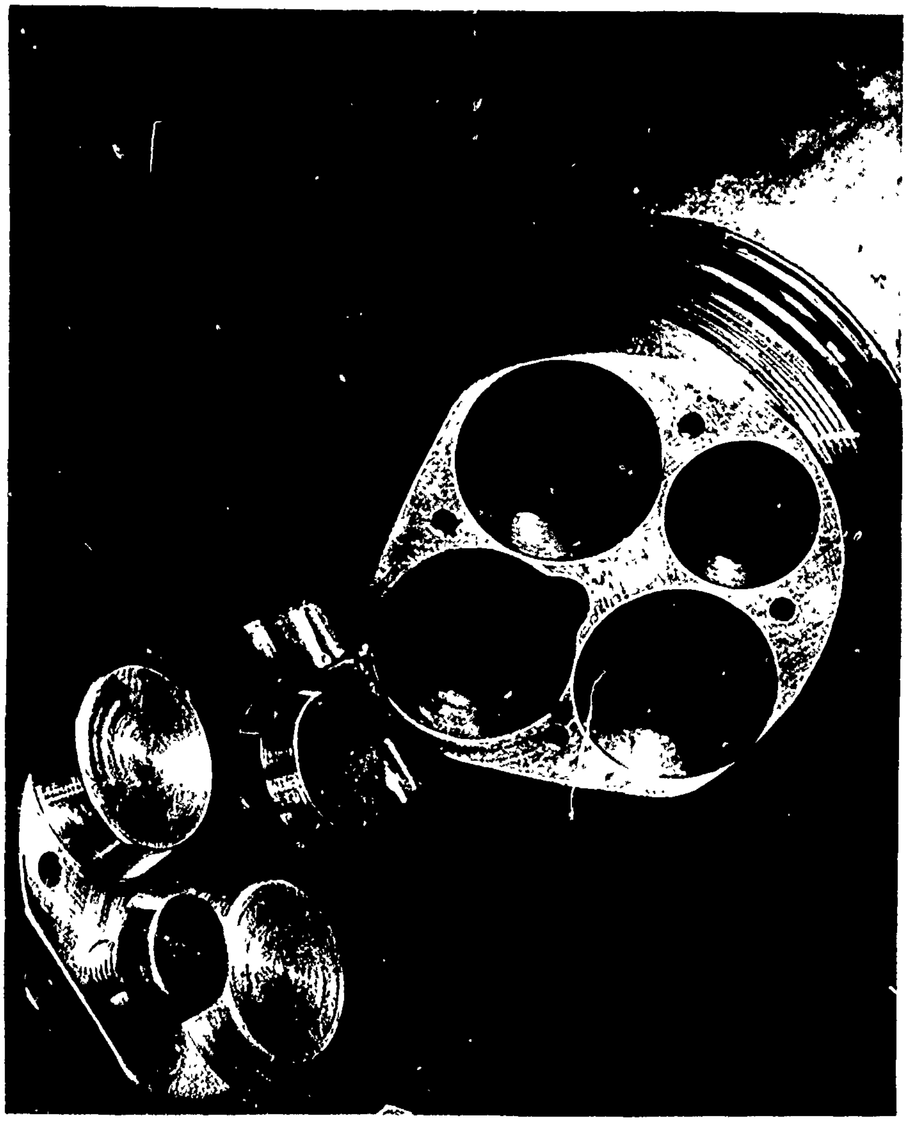


FIG. 51. Nozzle Plate.

methods consisted of bonding aluminum rails to an aluminum tube, bonding aluminum rails to a mandrel-wrapped fiberglass tube, and making an all-fiberglass tube.

During this time, hot-extruded tubes.were produced and although they require considerable machining, this process proved more economical than the experimental fabrication methods.

The launcher tube (Fig. 32) has a constant inside diameter. An insert is pressed into the tube and secured by screws into the breech closure fitting. This provides a ridge for the tangs of the nozzle sleeve to secure the motor tube to the launcher tube. The tangs are held in position by pressure of the spring loaded breech can. When the booster gases pressurize the breech volume, the spring is compressed, lowering the breech can,which releases the tangs from the insert and allows the motor tube to move out of the launcher tube.

The launcher tube has 32 holes capable of adapting any one of over 10 Martin-Baker seat attachment configurations presently in Navy

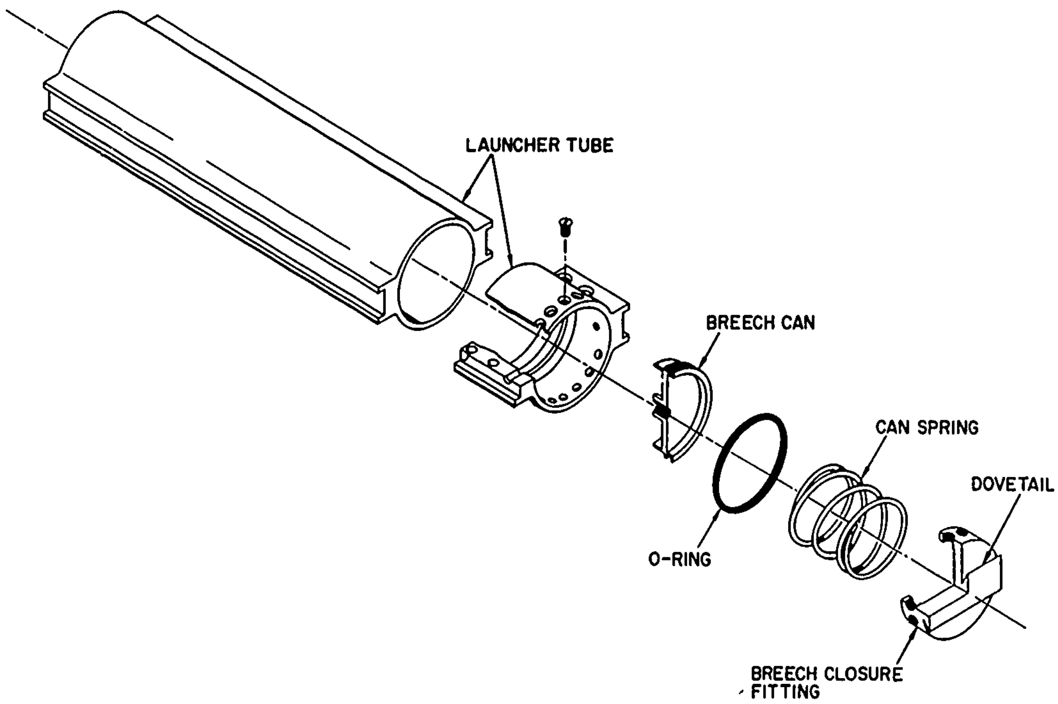


FIG. 32. Launcher Tube Assembly.

aircraft. In addition, the breech closure has a dovetail which allows the attachment of a yoke for installation in certain aircraft, or the deletion of the yoke where floor clearance is critical.

Shipping Container

The Shipping Container Mk 269 Mod 0 is capable of transporting two loaded Mk 2 Mod 0 catapults as shown in Fig. 33. The reusable shipping container is constructed of metal, with rubber supports at the fore and aft ends to provide vibration isolation. The catapults, with their firing mechanism guards in place, are positioned in the container with head ends reversed. Metal straps are used to secure the cover to the body of the shipping container.

QUALIFICATION

The Rocket Catapult Mk 2 Mod 0 was subjected to various environmental and handling tests. The rocket catapults were then static-fired on modified Mk 1 Mod 0 test equipment to determine any effects on performance.

During the development program, a Mk 34 Mod 0 firing mechanism was used exclusively in static tests. A pressure transducer was attached to the heavy steel mechanism to monitor internal ballistics of catapult, and to monitor sustainer motor pressure.

Functional Tests

HYDROSTATIC. Five final design Mk 2 Mod 0 booster tubes were hydrostatically tested to destruction. Each ultimate failure occurred at one of the five milled fl s for controlled burn-through. The average failure pressure was 6,400 psi.

FIRING MECHANISM. The sear pull-force required to actuate the firing mechanism averages approximately 31 pounds. This test was performed on fifteen units using a 20 in/min Scott Tester. However, redesign of the firing mechanism is presently in progress to reduce the sear pull-forces to about 20 pounds, to be compatible with the F4H installation.

UNDERWATER. Tests were conducted under 25 feet of water, at the Air Crew Equipment Laboratory (ACEL). The Mk 2 Mod 0 functioned normally, withstanding the hydrodynamic forces and adverse loads of ejection through an aircraft canopy.

SIMULATED POSITIVE 6 g PULL-UP. The Mk 2 Mod 0 catapults were fired against two 2.75-inch rockets. The catapults functioned normally against the combined thrust of 1,700 pounds.

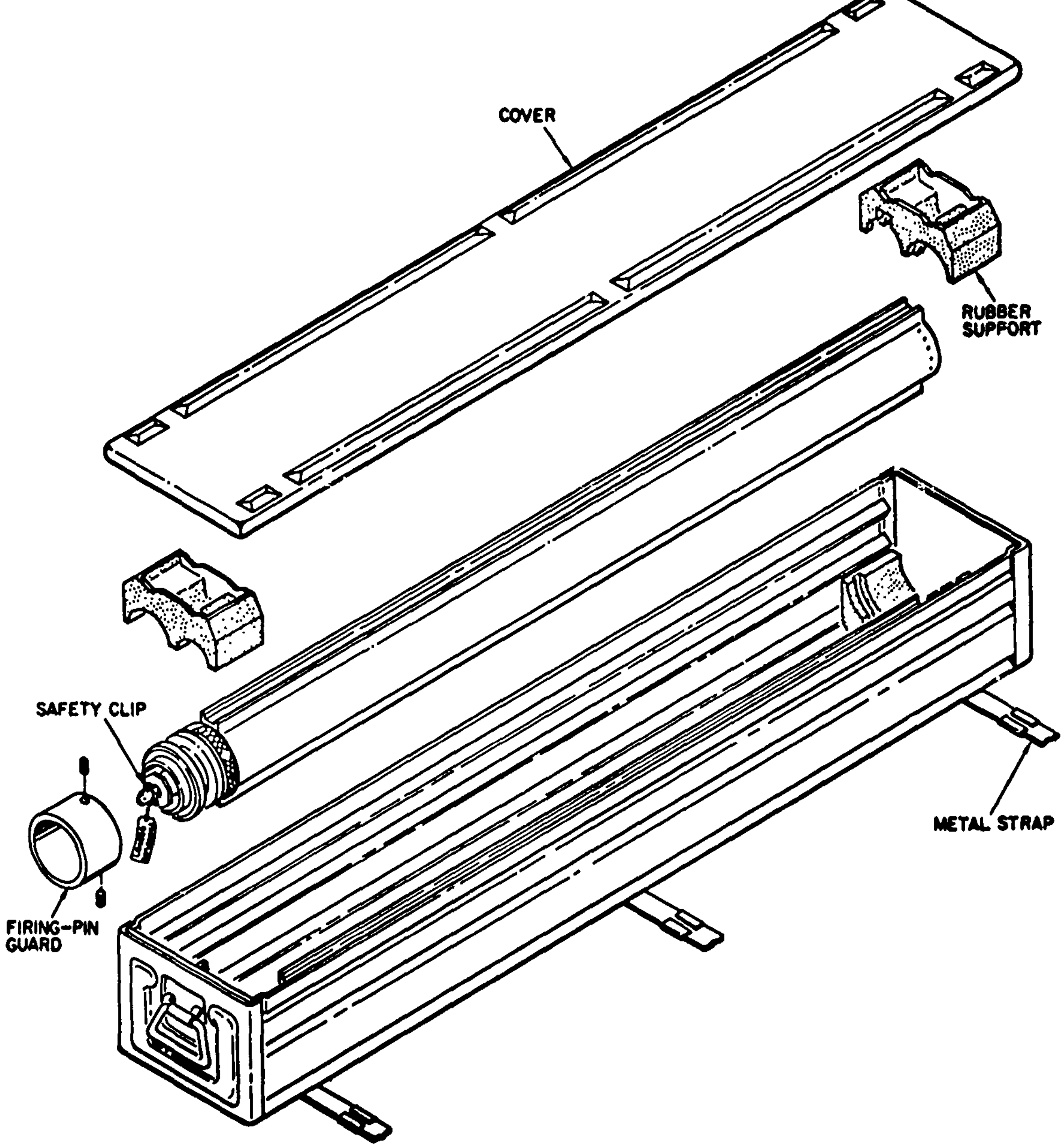


FIG. 33. Shipping Container Mk 269 Mod 0.

IMPACT LOAD TEST. The aluminum launcher tube produced by the hot-extrusion method was subjected to 40g impact load tests. These tests, conducted at ACEL and at Grumman Aircraft Engineering Corp., were successful. In addition, the early hot-extruded launcher tube with a concave rail design and the tube with aluminum rails bonded to an aluminum tube successfully passed the 40g load test.

ROUGH HANDLING AND DROP TEST. Fourteen catapults were dropped from 40 feet, 15 feet, and 27 inches. A 40-foot drop on the catapult head-end resulted in ignition. Catapults dropped 40 feet on the aft end, side, or in shipping containers did not ignite. Catapults dropped 15 feet suffered severe mechanical damage. Catapults dropped head-end down from 27 inches in shipping container were successfully static-fired at 70°F.

GUNFIRE. Two Mk 2 Mod 0 catapults were ignited and the motor tube ruptured when hit with 30-caliber projectiles.

BONFIRE. Two catapults were placed in a bonfire of fuel oil and wood. Ignition occurred when the catapults reached a recorded temperature of 1100°F.

FULLY RESTRAINED FIRING. A rocket catapult was fired with the rocket motor fully restrained in the launcher. Because of the fixed breech volume caused by the secured motor, the booster pressure increased until the weakened sections of the booster tube ruptured. The sustainer motor was ignited causing subsequent destruction of the catapult.

Environment

Forty-eight loaded catapults were subjected to the following test conditions:

1. Aging at 130°F for 10 days.
2. Five temperature cycles from -65 to 165°F.
3. Sand and dust in accordance with Procedure I, Specification MIL-E-5272.
4. Salt spray in accordance with Procedure I, Specification MIL-E-5272
5. Humidity in accordance with Procedure I, Specification MIL-E-5272.
6. Combinations of the above conditions.

Sixteen catapults were fired at -65° F, resulting in two malfunctions caused by head-end burn-through. Sixteen catapults fired at ambient temperature and sixteen fired at 165° F functioned normally.

ACCEPTANCE TEST

The acceptance test program was conducted to gain approval for unrestricted off-station air-firing usage.

Sixty Mk 2 Mod 0 catapults were selected at random from a loaded prototype production lot of 85. Before testing, eight catapults were subjected to a vibration environment. Although vibration tests were not required for acceptance, it was desired to confirm the modifications made during the qualification program. One catapult at each temperature extreme (-65 and 165° F) was subjected to aircraft vibration tests in accordance with Procedure XII, Specification MIL-E-5272, and six catapults were subjected to the transportation vibration schedule, Specification MIL-E-5272. All of the rocket catapults tested fired normally over the temperature range of -65 to 165° F.

EXPERIMENTAL PRODUCTION

Processing and production equipment required for the Mk 2 Mod 0 is, for the most part, Mk 1 Mod 0 equipment. Loading jigs and fixtures were modified for use in loading the Mk 2 Mod 0. New tooling was required for processing the candy bars.

APPENDIX A

List of Documentation

MK 1 MOD 0

Drawings by LD:

LD 269397	Loaded Assembly
LD 269398	Catapult, Aircraft Ejection Seat, Rocket, Mk 1 Mod 0 (inert)
LD 269399	Firing Mechanism, Rocket, Mk 28 Mod 0
LD 268039	Igniter, Rocket Motor, Mk 250 Mod 0
LD 268043	Booster Charge
LD 268053	Auxiliary Ignition Charge
LD 269093	Container Mk 217 Mod 0

MK 2 MOD 0

Drawings by LD:

LD 268141	Mk 2 Mod 0 Catapult-Loaded Assembly
LD 268140	Mk 2 Mod 0 Catapult-Empty Arrangement
LD 268144	Mk 195 Mod 0 Igniter-Loaded Assembly
LD 269488	Mk 196 Mod 0 Igniter-Loaded Assembly
LD 268143	Mk 69 Mod 0 Propellant Grain
LD 268142	Mk 29 Mod 0 Firing Mechanism
LD 268126	Mk 269 Mod 0 Shipping and Storage Container

Specification and Ordnance Data (OD):

WS 1581	Purchase Description Mk 2 Mod 0 Loaded Catapult
OS 11312	Description and Requirements for HE X-12 Propellant
OS 9765B	Description and Requirements for Boron Potassium Nitrate
OS 11604	Description and Requirements for Ethylcellulose Inhibitor

OD 15365	Instruction for Loading Mk 2 Mod 0 Catapults
OD 15374	Adiabatic Ignitability Tester
OD 24521	Preparation of Binder (PMVT)
WS 1585	Purchase Description for Mk 196 Mod 0 Igniter
OS 11295	Purchase Description for Zirconium Lead Dioxide
OS 11296	Description and Requirements for PMVT

Ordnance Classification of Defects (OCD):

1560144	1211494	652185	1517270
1211483	1516193	652148	1517373
1211484	1517133	1296827	1211498
1211486	1517134	1296829	1211499
1211487	1517182	1517184	1516199
1211488	1517183	1517185	458615
1211489	650948	1516192	1516200

APPENDIX B

Definitions
(Refer to Fig. 7)

BOOSTER

Ignition Delay

Ignition delay (ID) is the time between the initial applied current to the seal pulling charge (Mk 1 Mod 0 Squib) and the time at which sustained pressure in the launcher breech is first observed on the pressure - time curve. Ignition delay is expressed in milliseconds.

Maximum Thrust

The maximum thrust is the highest thrust during the booster burning cycle as scaled from the thrust - time curve. Maximum thrust is expressed in pounds.

Maximum Pressure (P max.)

The maximum pressure is the highest pressure during the booster burning cycle as scaled from the pressure - time curve. Pressures are to be expressed to the nearest psig and measured at the launcher breech of the loaded rocket catapult.

Thrust Rise

The thrust rise is determined on each test from the thrust - time record. It is defined as $\Delta F/\Delta t$ and represents the maximum positive slope measured over any 30-ms period between the time at which the thrust trace departs from zero thrust and the time of maximum thrust.

Maximum Pressurization Rate

The maximum launcher tube pressurization rate is determined on each test from the pressure - time record. It is defined as $\Delta P/\Delta t$ and represents the maximum positive slope measured over any 30-ms period between the time which the pressure trace departs from the zero pressure and the time of maximum pressure:

1. If time of P max occurs at 30 ms: rate = $\frac{P\ max}{30}$

2. If time of P max occurs at $>$ 30 ms: rate = $\frac{P_1}{30}$

(Where P_1 is equal to pressure corresponding to Δt of 30 ms).

3. If time of P max occurs at $<$ 30 ms: rate = $\frac{P\ max}{30}$

Launch Time

Launch time is the time required for the motor to clear the launcher tube. Launch time, expressed in milliseconds, is measured from the time the sustained launcher tube pressure trace departs from (0 psig) and ending when the sudden drop in launcher tube pressure first occurs.

Thrust - Time Integral

The thrust - time integral is the area under that portion of the thrust - time curve for the booster charge bounded by the launch time limits as defined.

Pressure - Time Integral

The pressure - time integral (PTI) is the area under that portion of the pressure - time curve for the booster charge bounded by the launch time limits as defined.

SUSTAINER MOTOR

Ignition Delay

Ignition delay is the time between launch and ignition of the sustainer charge. It is measured as the time between the sudden drop in pressure in the launch breech and when the internal pressure of the sustainer motor reached 500 psig on the pressure - time trace. Ignition delay is expressed in milliseconds.

Maximum Thrust

The maximum thrust is the highest thrust during the motor burning cycle as scaled from the thrust - time curve. Maximum thrust is expressed in pounds.

Maximum Pressure (P max)

The maximum pressure is the highest pressure during the motor burning cycle as scaled from the pressure - time curve. Pressures are to be expressed to the nearest psig.

Maximum Pressurization Rate

The maximum sustainer motor pressurization rate is determined on each test at minus 65° F from the pressure - time record. It is defined as $\Delta P/\Delta t$ and represents the maximum positive slope measured over any 30-ms period between the time at which the pressure trace departs from zero pressure and the time of maximum pressure.

Action Time

Action time (t_a) is the time, expressed in milliseconds, during which the sustainer motor pressure exceeds 500 psig at start of burning and ending when the pressure falls below 1,000 psig at the end of burning.

Thrust - Time Integral

The thrust - time integral is the area under that portion of the thrust - time curve for the sustainer motor bounded by the action time limits as defined.

Pressure - Time Integral

The pressure - time integral is the area under that portion of the pressure - time curve for the sustainer motor bounded by the action time limits as defined.

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